THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME LXVII JUNE 1928 NUMBER 5

FURTHER WORK ON INTERSTELLAR CALCIUM[1]

By OTTO STRUVE

ABSTRACT

Intensities of the calcium line K have been estimated in 1718 stars of spectral type O–B3, and in 338 stars of later spectral subdivisions. This material has been used for the derivation of systematic errors and for the determination of the precision of such intensity estimates.

After applying all necessary corrections the material was divided into *groups according to spectral type and according to apparent magnitude.* There appears to be a marked *increase in the intensity of detached K for fainter stars, and for earlier spectral types.* Be stars have also stronger calcium lines than absorption B stars. Several groups of *physically connected stars* were investigated separately, but there appears to be no certain evidence that luminosity or spectral type affect the intensity of K. The results were checked by means of the later types, and by means of estimates made on a stellar line in the vicinity of K. The various effects were not present in these instances, and their intensities closely followed the requirements of the theory of ionization.

It was proposed to *neglect all sources affecting the intensity of detached K, save only the distance of the star,* thus putting $I=f(D)$. This relationship was evaluated *graphically* from groups of stars whose distances are known with sufficient precision. It was then used for the derivation of distances and absolute magnitudes of certain other groups of stars. The results derived in this way are so consistent with other methods that *the assumption $I=f(D)$ seems justified.*

In my paper on "Interstellar Calcium,"[2] published last year, I have given an outline of the problem presented by the peculiar lines of ionized calcium in the spectra of the hottest stars. The intensities of the detached lines, discussed at that time, led to a number of interesting results, and it seemed advisable to undertake a new investigation of the whole problem, especially planned to cover the fol-

[1] A short abstract of this paper appeared in *Harvard College Bulletin,* No. 857, p. 11, 1928.

[2] *Contributions from the Mount Wilson Observatory,* No. 331, 1927; *Astrophysical Journal,* **65,** 163, 1927.

lowing points: (1) general expansion of the observational material, (2) extension of the work to the southern hemisphere, (3) extension to fainter stars, (4) special precautions to avoid systematic errors. It was my intention to study the following: (1) precision of the method, (2) physical significance of the estimated intensities, (3) regional effects, (4) relation between the intensities of the detached lines and the distances of the stars, (5) relation between luminosities and intensities, (6) relationship between ordinary stellar and peculiar detached lines.

I. THE MATERIAL

In my former paper I utilized estimates of the intensity of the line K, made from slit spectrograms, for 321 stars. Since it would not have been possible to accumulate a much larger number of slit spectrograms within a reasonable length of time, it seemed desirable to utilize objective-prism spectrograms.

Earlier work on line intensities undertaken at the Harvard College Observatory, notably by Miss C. H. Payne,[1] led to the belief (later substantiated by Miss Payne) that the Harvard collection of spectrograms would be admirably suited for such a study. Through the kindness of Director Harlow Shapley I was given the opportunity to make use of this fine collection of photographs.

In the preparation for this work a list was made from the *Henry Draper Catalogue and Extension* of all stars of spectral type $B3$ or earlier—about 2100 in number. In most cases the estimates were made on the same plates that had been used by Miss Cannon in her work on stellar classification, but in a number of cases additional plates were consulted. I would estimate the total number of separate plates used in this work at 1500.

The plates varied greatly in dispersion and scale, as will be seen from Table I. In order to avoid systematic differences, the various series of plates were kept separate, and material was provided for a study of the systematic corrections and relative merits of the dispersions.

The intensity of the calcium line K was derived in essentially the same manner that was used previously for the slit spectrograms.

[1] *Harvard College Observatory Circular*, No. 252, 1924.

The scale of estimates is an arbitrary one, but it was adjusted as nearly as possible to that of the slit spectrograms. I had originally based my scale on the standard of Vega, calling the intensity of stellar K in this star 10. One unit of the scale corresponds, then, to the smallest perceptible difference in intensity.

In the present work I proceeded in a similar manner. For the objective-prism plates of high dispersion (series X and C) I selected

TABLE I

DISPERSIONS USED

Designation of Series	Linear Average Dispersion ($H\zeta - H\beta$)	Instrument
C (long)	44 A per mm	11-inch Draper
C (short)	49	11-inch Draper
X (long)	36	13-inch Boyden
X (short)	41	13-inch Boyden
I	150	8-inch Draper
B	320	8-inch Bache
B′	150	8-inch Bache
MF	320	16-inch Metcalf

as standard a plate (C 15903) of the star 9 Cephei (α $21^h35^m.2$, δ $+61°38'$; B2p; 4.7 mag.) for which K was estimated as 10.[1] This avoided the use of a very bright star, such as Vega, and at the same time gave the advantage of having as standard a narrow detached line, in place of one of stellar origin. The scale is practically identical with the one based on Vega as standard, but an accurate comparison will be given farther on. The scale plate was frequently consulted during the work, but it did not appear necessary to consult it each time that an estimate was being made.

For the small-dispersion plates (series I, B, B′, MF) the procedure was somewhat different. The size of the plates and the number of stars are such as to render an actual comparison with a standard plate practically impossible. Furthermore, the appearance of the spectra varies so greatly on account of differences in focus, width of spectrum, etc., that an abstraction to ideal conditions must necessarily be made mentally. I have, therefore, used a purely mental scale, checked by frequent estimates on Ao stars. For these I as-

[1] Intensity given as 9 in *Mt. Wilson Contr.*, No. 331, 1927.

sumed a mean intensity of 10, in agreement with my previous standard of Vega. The scale is, therefore, similar to that of the slit spectrograms, but material for a determination of systematic errors was also secured.

Although most of the estimates apply to stars of early type, I have made for all series of spectrograms a certain number of estimates on stars of later spectral subdivisions, from B5 to A3. These were used for the derivation of systematic corrections, as well as for a study of the intensities in these later subclasses.

In order to distinguish effects due to "interstellar" conditions from those originating in the instrument, and from those that naturally occur under the varying conditions of stellar atmospheres, I selected a line of ordinary stellar origin, λ 3924, listed in Miss Payne's card catalogue as being due to Si^{++}, and estimated its intensity on every plate on which K was observed. The maximum intensity of this line, comparable to that of K, is reached in subdivision B3. If there are any photographic or instrumental effects, such as that of underexposure suspected in my earlier paper,[1] this line will also be subject to them. The scale used for the Si^{++} line was identical with that for K. In spectra of very small dispersion the two lines are almost blended (series B and MF), and this caused considerable uncertainty in the estimates. However, great care was used to make the estimates for the two lines independent of each other, and I believe that this was achieved in most cases.

Since both lines are always faint, they were identified by means of a ruler, on which were marked the Balmer lines of hydrogen, with an index in the position of K. By matching the lines on the ruler with those of the star, the position of K was shown by the index. Misidentifications were thus avoided.

For each star I estimated the quality of the plate, on a scale of 5 (5 standing for best quality), and the photographic density in one of the following six divisions: very weak, weak, normal, strong, very strong, overexposed. The estimate of "quality" was based chiefly on the general visibility of lines in this and nearby stars, in the region of K, and included the effect of "density." The two will later be shown to be closely correlated.

[1] *Op. cit.*, p. 14.

TABLE II

MATERIAL ON STARS OF SPECTRAL TYPES O–B3

α	No. of Stars	No. of Estimates	α	No. of Stars	No. of Estimates
0^h	33	54	12^h	87	132
1	13	22	13	61	132
2	41	82	14	47	85
3	41	97	15	50	99
4	31	62	16	126	195
5	116	267	17	119	174
6	120	207	18	104	172
7	123	201	19	77	134
8	96	134	20	112	214
9	34	50	21	57	213
10	100	172	22	39	125
11	66	93	23	25	46

Total number of stars: 1718.
Total number of estimates: 3153.
Number of stars observed at Harvard: 1677.
Number of stars observed with slit spectrographs: 329.
Number of estimates at Harvard: 2582.
Number of estimates on slit spectrograms: 571.

TABLE III

MATERIAL ON TYPES B5–A3

Type	No. of Stars	No. of Estimates
B5	150	180
B8	63	69
B9	41	45
A0	59	60
A2	21	22
A3	4	4

Total number of stars: 338.
Total number of estimates: 380.

TABLE IV

DISTRIBUTION OF ESTIMATES ACCORDING TO QUALITY			DISTRIBUTION OF ESTIMATES ACCORDING TO DENSITY			
Q	No.	Per Cent	*D*	No.	Per Cent	Mean Quality
1	164	6.3	o.c.	55	2.1	2.78
2	462	18.0	v.s.	113	4.4	3.34
3	1329	51.7	s.	347	13.5	3.41
4	463	18.0	n.	1640	63.8	3.16
5	152	5.9	w.	268	10.4	2.21
			v.w.	147	5.7	1.32
Mean	.....	.....	.....	.....	.....	2.99

In most of the present work I have also made use of the data from slit spectrograms. They form only a small proportion of the whole, but their scale has been accepted as fundamental, and all numerical data will be expressed in that scale.

Tables II, III, and IV show the distribution of the material according to various characteristics.

II. DETERMINATION OF SYSTEMATIC DIFFERENCES

a) *Corrections for "quality."*—In my former paper[1] it was shown that, beginning at a certain limit, underexposure tended to produce

TABLE V

CORRECTIONS FOR "QUALITY"

SERIES	*Ca*+			*Si*++		
	$Q=1$	$Q=2$	No.	$Q=1$	$Q=2$	No.
C	0.6	1.2	65	0.9	1.8	32
X	.5	0.9	399	.8	1.6	356
I	.0	.0	128	.4	0.8	127
B′	.0	0.0	16	.4	.8	16
B	0.8	1.7	11	0.0	0.0	11
Weighted mean	0.5	1.0	.....	0.7	1.4	.....

Add corrections to estimated intensity, if the quality is less than normal, and subtract, if the quality is better than the average.

fainter lines. A similar result was reached by Miss Payne and Mr. Hogg.[2] Since this error is particularly dangerous in an investigation of the intensities as function of apparent magnitude, I have determined the differences in intensity due to variations in the estimated "quality." The results were derived separately for K and *Si*++ λ 3924, and are summarized in Table V. If the differences in quality are designated by ΔQ and the corresponding differences in intensity by ΔJ, the supposition was made that the relation between them is of the form

$$\Delta Q = \text{Const.}\ \Delta J\ .$$

This is a sufficiently close approximation.

[1] *Ibid.*, p. 6.

[2] *Harvard College Observatory Circular*, No. 304, p. 6, 1927.

It is surprising that the corrections for quality are appreciably larger for the Si^{++} line than for K. Apparently, in making the estimates of quality I was somewhat under the influence of the spectrum itself and, therefore, rated stars with good lines higher than those with poor ones. The effect is in line with my previous results[1] which showed that the appearance of the calcium line was independent of the quality of the other star lines. This is an additional proof of the independent origin of the calcium lines. Assuming my previous results to be correct, namely, that the intensity of the Ca^{+} line is entirely independent of the intensities of the stellar lines,[2] it is evident that the corrections for K given in Table V are due to "quality" only, while those for the Si^{++} line are due to "quality" plus the effect of character of spectrum (diffuse or sharp lines). The intensities should, therefore, be corrected by values found for K.

The necessary corrections were applied to the estimates, reducing them to quality 3, corresponding to a normal spectrum. In no case does the correction exceed 1 unit on my scale.

b) *Precautions against selection.*—A certain danger to the results could have arisen from the fact that many poor or out-of-focus plates had to be discarded. The tendency would undoubtedly have been to utilize underexposed or poor plates showing strong K and

[1] *Popular Astronomy*, **34**, 158, 1926.

[2] This assumption may require an explanation. In my previous paper (*loc. cit.*) I found that the coefficient of correlation between the intensity of one particular stellar line (Si^{++} λ 4553) and the estimated character of spectrum amounted to +0.47. The coefficient of correlation between the intensity of detached K and character of spectrum was found to be +0.29. This would seem to indicate a relationship between K and the atmosphere of the star. However, there appeared to be a positive correlation between character of spectrum and apparent magnitude ($r = +0.2 \pm 0.05$), and it was therefore concluded that the estimates of character of spectrum were influenced by outside factors, such as underexposure, flexure of the spectrograph, photographic effect, etc. These effects naturally influence the estimated intensity of *K*. It appears probable that the major part of the coefficient of correlation, $r = +0.29$, is due to such outside factors. Whether a small positive correlation between character of spectrum and intensity of *K* would remain cannot at present be ascertained. If the intensity of K depends on absolute magnitude (or distance) and if sharper and stronger stellar lines point to higher luminosities, such a correlation might be expected. It is certain, however, that the coefficient of correlation would be much smaller than 0.29. Since the maximum correction in no case exceeds 1 unit, and since, furthermore, the distribution of the qualities is such that only a small percentage of the estimates need any correction at all, no appreciable error can result.

to discard spectra of the same quality but not showing K. This would have given a predominance of strong lines for the fainter stars, thus operating in the same sense in which any possible distance effect might act.

To avoid this source of error, I have adopted the rule of making estimates always and only then, if the continuous spectrum could be seen at $H\zeta$. This rule does not refer to the slit spectrograms, but the fact that intensities from Yerkes plates do not materially differ from those obtained at Victoria and at Mount Wilson proves that they, too, are free from this source of error. Indeed, if any such error existed, it would be present in 5–6 mag. for the Yerkes plates, but would not appear in the Victoria and Mount Wilson material until about 7 or 8 mag.

c) Change of scale as a function of time.—It was considered necessary to investigate whether my scale of estimates had been subject to slow changes, similar to those frequently encountered by observers of variable stars. This is especially true for the series of smaller dispersions, where my scale was largely a mental one, and was not constantly checked by means of a standard plate.

To provide the necessary material I have repeated, at various times, a considerable number of estimates from the same plates. These are most numerous for the I series, for which I estimated 109 stars at the beginning and at the end of the work. The systematic differences come out as follows:

Series		Unit	Stars
I	Calcium	Beginning–end = −0.09	(109)
	Silicon	Beginning–end = +0.44	(107)
C	Calcium	Beginning–end = +1.0	(10)
X	Calcium	Beginning–end = −0.67	(3)

For series I the differences are negligible, while for the other two series the number of stars is so small that no real significance can be attributed to them. These corrections have accordingly been neglected in the results.

d) Systematic differences between series.—These are summarized in Table VI. In most cases these differences are smaller than 1 unit, and in some the signs are contrary to one another. It is, therefore, believed that my initial attempt to make the scales identical for all

series used had been successful, and that the recorded differences are mainly due to accidental errors. I have left the estimates in their original form and have not applied additional corrections for the different series.

It will be noticed, however, that in specially selected groups of stars, each consisting of one given series of plates, systematic dif-

TABLE VI

DIFFERENCES BETWEEN SERIES

Calcium			Silicon		
S−C=+0.15..	Mean dev. 1.32	No.=127	.....	.....	.....
S−X= .10..	0.90	22	.....	.....	.....
S−I= .12..	2.04	178	.....	.....	.....
S−B′=+ .21..	1.36	7	.....	.....	.....
S−B=−0.67..	1.33	3	.....	.....	.....
C−X=−0.74..	1.49	8	C−X=+0.88..	1.55	6
C−I=+0.26..	1.59	69	C−I=−0.62..	1.60	52
C−B′=+2.05..	2.14	11	C−B′=−2.06..	2.06	7
C−B=−0.50..	1.50	3	C−B=−1.33..	2.67	3
X−B′=+1.13..	1.95	56	X−B′=−0.37..	1.69	45
X−B= 1.36..	2.09	34	X−B=−1.13..	1.78	31
X−MF=+0.40..	1.60	3	X−MF=−1.57..	2.57	3
I−B=−0.50..	1.83	3	I−B=−0.33..	0.33	3
B′−B=+0.11..	1.70	53	B′−B=−0.07..	1.63	53
B′−MF=−3.03..	3.03	7	B′−MF=+ .91..	1.94	7
B−MF=−1.72..	2.80	12	B−MF=+0.03..	1.80	12

The tabular values represent the means for every combination of two estimates for each star having intensities from various series. The mean deviation is the mean difference for every two estimates.

ferences amounting to about 1 unit are possible, even though the number of stars may be large. This is especially important for comparison of regions situated in the northern and in the southern hemispheres.

Table VI seems to reveal a tendency to show opposite signs for Ca^{+} and Si^{++} in the same series. This may be real, and may be traceable to psychological errors of the observer.

III. PRECISION OF THE ESTIMATES

The scale of estimates had been selected in such a way that one unit corresponded to the smallest perceptible difference in intensity.

It is expected, therefore, that the probable error of one estimate will be of the order of one unit.

The probable error of one estimate was computed for all stars having six or more separate estimates. The individual values fluctuate slightly as a function of the intensity itself, but the mean is ± 0.90. This value may be a little too small, since, in general, only the brighter and, therefore, better-exposed stars have as many as six estimates each. For most of the fainter stars the estimates are few and the formulae of statistics do not apply because of the nonfulfilment of the condition of large numbers.

If we compute the probable error from a small sample of a given population the value obtained will necessarily be too small, since the computed mean will not be sufficiently close to its real value. In Table VI the mean deviations were given for samples of two individuals each, and represent the difference between them. According to Peters' formula we have:

$$r_0 = \frac{0.8453 \Sigma \Delta}{n \sqrt{n-1}},$$

where Δ refers to the true value of the mean. Evidently, if we take the mean deviations from Table VI, as they stand, we would exaggerate the probable error. The computed mean from each sample of two would lie halfway between them and would make the resulting Δ smaller than they really are. Therefore, we have:

$$\frac{0.8453 \Sigma \Delta}{2n \sqrt{n-1}} < r_0 < \frac{0.8453 \Sigma \Delta}{n \sqrt{n-1}}.$$

The exact determination of r_0 is a difficult problem of modern statistics if the samples are small, as they are in our case. But a sufficiently close value can be found by assuming[1]

$$r_0 = \pm 0.75 \frac{0.8453 \Sigma \Delta}{n \sqrt{n-1}}.$$

[1] The probable errors in my former paper (*op. cit.*, p. 6) were also computed from small samples, although there the number of individuals was larger than two. The real probable errors would be somewhat larger than those given, that is, of the order of ± 0.75 unit, for all series considered at that time.

Substituting the values from Table VI and taking the average, we get:

$$r_0 = \pm 1.12 .$$

This agrees sufficiently well with the value of ± 0.90 found directly. We will assume as final value of the probable error of one estimate

$$r_0 = \pm 1.0 .$$

Since, on the average, we have for each star 1.54 estimates, the average probable error of one final intensity is given by

$$r = \pm \frac{r_0}{\sqrt{1.54}} = \pm 0.8 .$$

IV. PHYSICAL SIGNIFICANCE OF THE INTENSITIES

Errors of measurement necessarily produce a certain amount of scattering in the recorded intensities. A doubt might, therefore, arise as to whether the intensities have any real physical significance. In Table VII, I have collected data for a few of the better-known stars.

TABLE VII

INDIVIDUAL INTENSITIES FOR CERTAIN STARS

a) Stars with Strong Lines	
χ^2 Orionis	7, 7, 13
9 Camelop	10, 5, 10, 8, 10
λ Cephei	5, 7, 6, 6, 7, 8, 4, 6, 7, 8, 8, 4, 6
9 Cephei	6, 7, 10, 8, 10, 6, 5, 6, 6, 7, 9, 9
b) Stars with Faint Lines	
β Cephei	2, 0, 0, 0, 1, 0, 1
η Ursae Maj	1, 0, 0, 1
α Virginis	0, 1, 0, 0, 0, 0, 1, 0
π Scorpii	1, 1, 1, 1, 0, 0, 1, 1

The reality of the differences between the stars of Table VII can readily be verified by reference to any spectrogram, even one of small linear dispersion. We are thus justified in our assumption that there exist certain physical conditions producing strong detached

calcium lines in some stars, while in others the same lines are faint or even absent.[1]

Table VIII gives the frequency distribution of the observed intensities for all stars of spectral type O–B3. The computed characteristics are:

	Units
Mean intensity =	3.32
Standard deviation =	± 1.97

The skewness is appreciable but is of no special interest, as it obviously depends upon the scale employed. Since the distribution is discontinuously broken off at $I = 0$, and since, furthermore, the existence of a strong line is a "rare event," it can best be represented by one of Charlier's frequency curves of type B.

TABLE VIII

FREQUENCIES OF THE INTENSITIES OF K IN SPECTRAL TYPES O–B3

I.....	0.0–0.9	1.0–1.9	2.0–2.9	3.0–3.9	4.0–4.9	5.0–5.9	6.0–6.9	7.0–7.9	8.0–8.9	9.0–9.9	10.0–10.9	11.0–
No.....	95	250	341	429	293	161	62	38	23	7	12	7

The standard deviation found for the whole material corresponds to a probable error of 1.35. This is to be compared with the probable error of one intensity, $r = \pm 0.8$. If we designate the total dispersion by $\sigma = \pm 1.97$, the dispersion from inaccuracy of measurements by $\sigma_\epsilon = 0.8/0.674 = 1.2$, and the dispersion produced by cosmic causes by σ_c, we have:

$$\sigma = \pm \sqrt{\sigma_\epsilon^2 + \sigma_c^2},$$

or

$$\sigma_c = \pm \sqrt{\sigma^2 - \sigma_\epsilon^2}.$$

Substituting the values found above we find:

$$\sigma_c = \pm 1.6 \text{ units.}$$

[1] I take it for granted that in the samples of Table VII the calcium lines are actually "detached." Measurements of radial velocity prove this. In the following paragraphs we shall extend this assumption to faint stars, where the radial velocities are not known. There is no reason to assume that the fainter or more distant stars should show "stellar" calcium lines, when such lines are absent in the respective spectral classes for nearer stars.

The cosmic dispersion is thus found to be slightly larger, but still of the same order of magnitude as that due to the inaccuracy of the measurements. To separate the two effects it is necessary to form groups of stars in such a way that for each group the cosmic factors would remain constant. The dispersion due to the inaccuracy of the measurements is then reduced in inverse proportion to the square root of the number of stars included, while for the difference between two such groups the cosmic effect would come in with its full value.

V. THE EFFECTS OF APPARENT MAGNITUDE AND SPECTRAL TYPE

If we group all stars of spectral type O–B3 according to their apparent magnitude, we find average intensities as shown in Table IX.

TABLE IX

INTENSITY OF DETACHED K AS A FUNCTION OF APPARENT MAGNITUDE

Appar. Mag.	No.	Aver. Int.
0– 1	1	1.0
1– 2	10	0.97
2– 3	32	1.39
3– 4	42	1.85
4– 5	141	2.41
5– 6	205	2.91
6– 7	316	3.12
7– 8	389	3.60
8– 9	372	3.70
9–10	182	4.04
10–11	27	4.44
11–12	1	11.0

The run of the intensities is very smooth, as is illustrated by Figure 1. This shows that, with the precautions taken, the increase in intensity persists into the faintest apparent magnitudes. It is certain that the possibility of the lines becoming weaker for stars of apparent magnitude fainter than 7 (as suggested in my previous paper)[1] is now definitely ruled out.

We have the very remarkable fact that there exists a continuous increase in the intensity of detached K as we proceed from the

[1] *Contributions from the Mount Wilson Observatory*, No. 331, p. 13, 1927.

brighter apparent magnitudes to the fainter ones, and this increase amounts to 0.4 intensity unit for each stellar magnitude.

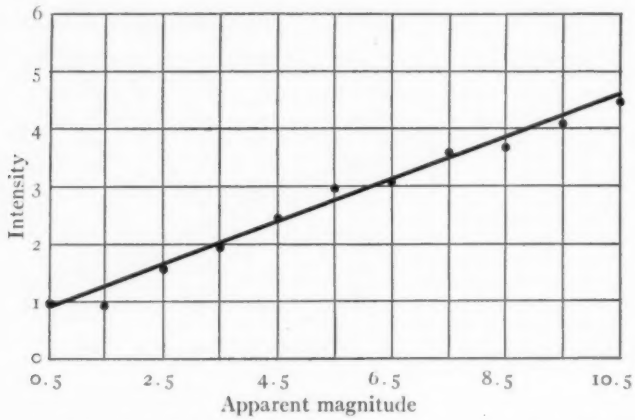

FIG. 1.—Intensity of detached calcium line K as a function of apparent magnitude.

By grouping all stars according to spectral type, we obtain the distribution shown in Table X. For convenience I have included the estimates made for the later types[1] and for the Si^{++} line 3924.

TABLE X

INTENSITY OF K AS A FUNCTION OF SPECTRAL TYPE

Spectral Type	No.	Intensity K	No.	Intensity Si^{++}
O	95	4.40	89	0.91
Bo	302	3.71	290	1.84
B1	66	3.13 −	60	1.91
B2	326	3.65 −	316	2.39
B3	929	2.97	885	2.97
B5	150	3.05	124	2.12
B8	63	3.83	51	1.07
B9	41	4.50	32	0.80
Ao	59	8.47	50	.46
A2; A3	25	19.98	14	0.07

It will be seen that the detached lines are strongest for type O and weakest for B3. This is contrary to the ordinary theory of ion-

[1] These have not been used in Table IX.

ization and can be regarded as an independent proof of the peculiar behavior of these lines.[1]

In interpreting the relations obtained it must be remembered that apparent magnitude has no independent physical significance. It is completely determined by the absolute magnitude M and the distance, in parsecs, D, through the relation

$$m = M + 5 \log D - 5 ,$$

or, since we may put $M = f(Sp)$,

$$m = f(Sp) + 5 \log D - 5 .$$

It is clear that the two relations found above are not independent. They may both be due to a distance effect, or to one of spectral type (or luminosity), or to the combination of the two.

TABLE XI

INTENSITY AND SPECTRAL TYPE

Appar. Mag.	O		Bo		B1		B2		B3	
	No.	*I*	No.	*I*	No.	*I*	No.	*I*	No.	*I*
0– 1	0	.....	0	.....	1	1.0	0	.....	0	.....
1– 2	0	.....	2	2.0	4	0.7	3	0.9	1	0.4
2– 3	3	0.9	6	1.2	5	1.8	7	1.4	11	1.4
3– 4	1	5.1	2	2.6	5	1.4	10	1.7	24	1.8
4– 5	6	3.9	9	2.6	11	3.0	18	3.0	97	2.1
5– 6	12	4.1	21	4.2	8	4.0	23	3.3	141	2.5
6– 7	17	4.2	45	3.4	11	4.2	42	3.2	201	2.9
7– 8	24	5.0	66	3.8	17	3.8	85	3.9	197	3.2
8– 9	19	4.8	94	3.9	4	3.0	87	3.9	168	3.4
9–10	9	3.8	55	3.7	0	.....	44	4.3	74	4.0
10–11	3	3.7	2	4.8	0	.....	7	4.4	15	4.6
11–12	1	11.0	0	.....	0	.....	0	.....	0	.....
All	95	4.40	302	3.71	66	3.13	326	3.65	929	2.97

Table XI shows the whole material divided according to spectral type and according to apparent magnitude. It will be seen that all spectral subdivisions behave essentially in the same manner, and

[1] It is strange to find that in all my tabulations (*Contributions from the Mount Wilson Observatory*, No. 331, p. 19; *Popular Astronomy*, **34**, 7, 1926) type B1 has an abnormally small intensity and B2 an abnormally strong one. It would seem that from the point of view of calcium intensities these two subdivisions should reverse their order. But this effect may be purely accidental.

that for each apparent magnitude the earlier types exhibit stronger lines than the later ones. This can be explained by assuming that the intensity I is a function of D only.

VI. EXAMINATION FOR SYSTEMATIC ERRORS

The foregoing conclusions seem sufficiently important to justify a careful scrutiny of the whole material for systematic errors. In a general way such errors are not very likely to occur. As we have seen, the only serious source of error is that due to differences in the

TABLE XII

INTENSITY OF $Si++$ λ 3924 AS A FUNCTION OF APPARENT MAGNITUDE AND SPECTRAL TYPE

Appar. Mag.	O		Bo		B1		B2		B3	
	No.	I	No.	I	No.	I	No.	I	No.	I
0– 1.....	0	.....	0	.....	1	3.2	0	.....	0	.....
1– 2.....	0	.....	2	0.5	4	1.6	3	2.6	1	1.5
2– 3.....	3	1.5	5	1.8	5	3.1	6	3.7	10	3.6
3– 4.....	1	0.5	2	2.0	5	1.9	9	4.0	23	3.6
4– 5.....	6	1.0	7	1.3	8	2.7	16	2.9	83	3.3
5– 6.....	10	1.2	19	1.6	6	1.6	20	2.9	132	3.0
6– 7.....	15	1.0	44	1.6	11	2.1	42	2.6	189	3.1
7– 8.....	23	0.7	65	1.9	17	1.2	83	1.9	191	2.6
8 –9.....	19	.8	90	2.1	3	2.2	86	2.3	168	3.1
9–10.....	8	.9	54	1.8	0	.....	44	2.4	73	2.7
10–11.....	3	0.7	2	2.2	0	.....	7	2.9	15	2.5
11–12.....	1	1.0	0	.....	0	.....	0	.....	0	.....
All....	89	0.91	290	1.84	60	1.91	316	2.39	885	2.97

series of plates. In the preceding discussion, however, the plates of different series have been mixed so thoroughly that no effect comparable to the one found could remain.

A more direct proof can be submitted. Table XII gives the intensities of the Si^{++} line λ 3924 arranged in a way similar to Table XI. The effect of apparent magnitude is absent, as would be expected, and the progression with spectral type is exactly that expected from the theory of ionization for a line of doubly ionized silicon, the general run being quite different from that of the detached K line.

Similar tables were constructed for the line K in later spectral

types as well as for the Si^{++} line. In both cases the effect of apparent magnitude is absent and the relation with spectral type is that required by the theory of ionization for lines originating in the atmospheres of the stars.

To check the results still further, I have excluded from the early types all plates of series B and MF because of their small dispersion. The results remain practically the same as in Table XI, showing a strong increase in intensity for the fainter stars, and a similar increase for the earliest spectral types.

Finally, I have tabulated the material separately for each observatory. The results are in good agreement, especially if one con-

TABLE XIII

INTENSITIES OF K FOR THE DIFFERENT OBSERVATORIES

Appar. Mag.	Yerkes	Mt. Wilson	Victoria	Harvard
0– 1	.....	.....	.....	(1.0)
1– 2	1.9	1.2	1.3	0.7
2– 3	1.9	1.6	2.2	1.3
3– 4	2.6	2.6	3.4	1.6
4– 5	3.0	2.5	4.0	2.3
5– 6	3.4	2.9	4.1	2.8
6– 7	.....	4.8	3.3	3.1
7– 8	.....	4.0	3.6	3.5
8– 9	.....	4.8	(2.0)	3.7
9–10	.....	(2.5)	(3.0)	4.1
10–11	.....	.....	.....	4.4
11–12	.....	.....	.....	(11.0)

siders the small number of stars for which slit spectrograms were available. A summary is given in Table XIII. Uncertain values, obviously affected by errors of underexposure or by the scantiness of the material, are placed in parentheses. The Harvard intensities run a little lower than those obtained from slit spectrograms, but the increase for faint stars is visible in all series. The inclusion of the slit spectrograms will tend rather to obliterate the effect than to accentuate it. Therefore, we can safely say that the effects of apparent magnitude and of spectral type upon the detached lines are real.

VII. REGIONAL EFFECTS

The final intensities for each star were entered on a diagram of coordinates, and the average for each square of 10° on the side were

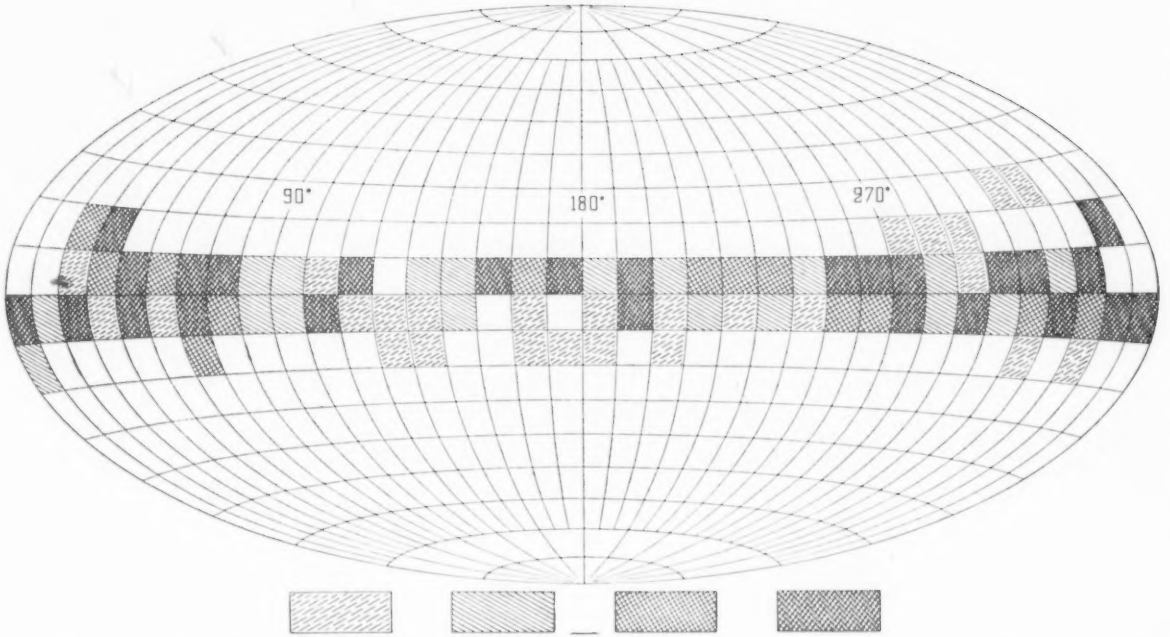

FIG. 2.—Galactic distribution of calcium intensities. The four different types of shading shown at the bottom of the diagram indicate, respectively: $I<2.8$; $2.8\leq I<3.2$; $3.2\leq I<3.7$; $3.7\leq I$. The galactic co-ordinates of the more important regions are:

Perseus	$l=100°$–$120°$;	$b=-10°$–$+10°$	(very strong)
Orion	160 –180	10 – –20	(very weak)
Monoceros	170 –180	0 – +10	(very strong)
Carina	250 –260	10 – 10	(strong)
Crux	260 –280	10 – 10	(very strong)
Scorpius	300 –320	10 – 10	(strong)
Sagittarius	330 –340	10 – 0	(strong)
Cygnus	30 – 50	–10 – 10	(very strong)
Cepheus	60 – 80	0 – +10	(very strong)

taken, provided that the number of separate estimates in a given square was not less than 5.[1]

A decided concentration of strong lines in Cygnus and Cepheus is shown, and an even more striking region of faint lines occurs in the southern portion of Orion. As these regions are especially rich in stars, the recorded difference of more than 3 units may be regarded as definitely established.

In a general way there seems to be a tendency for weak lines to predominate between galactic longitudes 80° and 250°, while stronger lines predominate in the other hemisphere. This difference is probably real, but I know of no way to prove that systematic errors have not crept into the results.

The more interesting groups of strong or weak lines are indicated in Figure 2. Attention should be called to the small region of strong lines corresponding to the double cluster in Perseus. This region is surrounded by areas of small intensity.

Whether the regional effects, as observed in Cygnus, Cepheus, Perseus, and Orion, are due to any real "calcium clouds," or whether they are due to differences in the average relative distances of the stars forming physical systems cannot be determined at this point.

VIII. PHYSICALLY CONNECTED GROUPS OF STARS

There are among the early B-type stars a number of physically connected groups or clusters. Some of these I have examined statistically in a recent paper,[2] where it was shown that the stars in each cluster may be regarded as being at the same distance from the sun. This refers especially to the groups in Cygnus, Perseus, and, from the investigations of Kapteyn, also to the group in Orion. Kapteyn's investigations make it probable that similar groups exist in the southern sky.

The intensities of the detached lines in every given cluster are thus independent of the distance. They enable us, therefore, to study the distribution separately for spectral type and luminosity,

[1] I am using this method according to a suggestion from Professor Frank Schlesinger.

[2] *Astronomische Nachrichten*, **231**, 17, 1927.

the latter being given by the apparent magnitude. Table XIV is self-explanatory.

TABLE XIV

GROUPS OF B-TYPE STARS

REGION: PERSEUS; α $1^h36^m-2^h44^m$; δ $+54°$ to $+61°$

Spectrum	Magnitude						
	4.5	5.5	6.5	7.5	8.5	9.5	Total
O	.....	.....	.....	.....	3.8(2)	7.5(1)	5.0(3)
Bo	.....	.....	2.5(3)	5.2(1)	5.0(5)	.....	4.2(9)
B1	.....	.....	2.3(1)	4.5(2)	1.0(1)	.....	3.1(4)
B2	.....	.....	5.6(1)	4.9(4)	4.0(4)	.....	4.6(9)
B3	.....	0.8(2)	3.2(3)	5.5(3)	3.8(6)	3.5(1)	3.6(15)
Total	.....	0.8(2)	3.1(8)	5.0(10)	4.0(18)	5.5(2)	4.0(40)

REGION: ORION; α $5^h12^m-5^h36^m$; δ $-8°$ to $+4°$*

Spectrum	Magnitude							
	1.5	2.5	3.5	4.5	5.5	6.5	7.5	Total
O	.....	1.5(1)	.....	.....	1.4(2)	.....	.....	1.4(3)
Bo	2.0(2)	1.7(1)	1.3(1)	0.0(1)	.....	.....	.....	1.4(5)
B1	.....	.....	1.5(1)	2.2(1)	1.5(1)	2.0(1)	.....	1.8(4)
B2	2.1(1)	.....	.....	1.1(1)	3.1(3)	.....	.....	1.9(5)
B3	.....	.....	.....	1.9(8)	2.1(8)	2.8(12)	2.2(9)	2.3(37)
Total	3.0(3)	1.6(2)	1.4(2)	1.7(11)	2.0(14)	2.8(13)	2.2(9)	2.1(54)

REGION: MONOCEROS; α $6^h24^m-6^h57^m$; δ $+1°$ to $+11°$

Spectrum	Magnitude							
	4.5	5.5	6.5	7.5	8.5	Total		
O	6.1(1)	.....	.....	.....	.....	6.1(1)	.....	.....
Bo	.....	5.0(4)	.....	.....	.....	5.0(4)	.....	.....
B1	.....	5.3(1)	.....	.....	.....	5.3(1)	.....	.....
B2	.....	.....	3.2(3)	5.2(8)	4.0(3)	4.5(14)	.....	.....
B3	.....	2.4(1)	3.1(3)	3.2(2)	4.0(2)	3.3(8)	.....	.....
Total	6.1(1)	4.6(6)	3.1(6)	4.8(10)	4.0(5)	4.3(28)	.....	.....

* Two stars fainter than 7.5 were included in the column 7.5.

TABLE XIV—*Continued*

REGION: CARINA; α $10^h4^m-11^h24^m$; δ $-55°$ to $-65°$

Spectrum	Magnitude							
	4.5	5.5	6.5	7.5	8.5	9.5	10.5	Total
O	.....	.....	6.6(2)	4.5(3)	4.6(6)	2.8(2)	.....	4.6(13)
Bo	.....	.....	3.2(3)	4.1(11)	3.7(11)	3.6(4)	.....	3.8(29)
B1	.....	.....	.....	3.9(3)	.....	.....	.....	3.9(3)
B2	.....	.....	1.5(1)	3.3(6)	3.9(11)	3.6(5)	.....	3.6(23)
B3	3.0(1)	3.7(6)	3.1(8)	3.4(6)	2.8(13)	3.2(8)	3.2(2)	3.2(44)
Total	3.0(1)	3.7(6)	3.5(14)	3.8(29)	3.6(41)	3.4(19)	3.2(2)	3.6(112)

REGION: CRUX; α $11^h42^m-13^h7^m$; δ $-56°$ to $-67°$†

Spectrum	Magnitude							
	4.5	5.5	6.5	7.5	8.5	9.5	10.5	Total
O	.....	4.0(2)	.....	.....	.....	.....	.....	4.0(2)
Bo	.....	.....	6.0(1)	3.3(7)	4.0(10)	4.1(17)	4.8(2)	4.0(37)
B1	.....	.....	4.0(1)	3.9(3)	.....	.....	.....	2.8(6)
B2	.....	.....	3.6(3)	4.5(4)	4.8(9)	3.8(4)	5.0(1)	4.4(21)
B3	1.4(4)	.....	2.7(3)	3.6(5)	3.0(17)	3.9(9)	.....	3.0(39)
Total	1.4(4)	4.0(2)	3.6(8)	3.7(19)	3.7(36)	4.0(30)	4.8(3)	3.7(105)

REGION: SCORPIUS; α $15^h57^m-17^h2^m$; δ $-35°$ to $-51°$‡

Spectrum	Magnitude							
	4.5	5.5	6.5	7.5	8.5	9.5	10.5	Total
O	.....	6.2(2)	4.6(3)	6.2(2)	6.0(1)	.....	.....	5.6(8)
Bo	.....	5.7(2)	2.2(3)	5.0(2)	4.0(4)	4.5(11)	.....	4.2(22)
B1	7.0(1)	.....	5.2(2)	4.0(1)	.....	.....	.....	5.4(4)
B2	.....	.....	4.0(1)	3.8(5)	4.1(6)	4.7(6)	3.8(2)	4.0(21)
B3	.....	3.0(1)	4.2(4)	3.9(14)	5.4(5)	4.2(7)	.....	4.1(32)
Total	7.0(1)	5.4(5)	4.0(13)	4.2(24)	4.6(16)	4.4(24)	3.8(2)	4.3(87)

† One star: I = 0.6 sp. B1; 1.5 mag.
One star: I = 0.6 sp. B1; 1.5 mag.
One star: I = 0.8 sp. B3; 2.5 mag.
‡ One star: I = 0.8 sp. B3; 2.5 mag.
One star: I = 0.6 sp. B2; 3.5 mag.

TABLE XIV—*Continued*

REGION: SAGITTARIUS; α $17^h49^m-18^h13^m$; δ $-18°$ to $-27°$

Spectrum	Magnitude							
	4.5	5.5	6.5	7.5	8.5	9.5	10.5	Total
O	.....	.....	3.2(2)	3.1(2)	.....	.....	.....	3.2(4)
Bo	.....	3.4(3)	4.2(1)	2.2(4)	5.0(1)	.....	.....	3.2(9)
B1	.....	5.7(1)	7.0(1)	.....	4.5(1)	.....	.....	5.7(3)
B2	.....	.....	3.0(1)	4.0(1)	3.3(3)	.....	.....	3.4(5)
B3	.....	6.0(1)	.....	2.1(4)	3.3(5)	.....	.....	3.1(10)
Total	.....	4.4(5)	4.1(5)	2.5(11)	3.6(10)	.....	.....	3.4(31)

REGION: CYGNUS; α $19^h44^m-20^h24^m$; δ $+34°$ to $+41°$

Spectrum	Magnitude							
	4.5	5.5	6.5	7.5	8.5	9.5	10.5	Total
O	4.4(1)	.....	3.5(1)	4.5(4)	4.5(1)	2.0(1)	.....	4.1(8)
Bo	.....	.....	4.3(1)	2.0(1)	3.2(2)	3.0(4)	.....	3.0(8)
B1	.....	.....	.....	4.1(1)	.....	.....	.....	4.1(1)
B2	2.4(1)	3.4(2)	4.6(2)	3.0(4)	3.3(5)	5.9(8)	2.5(2)	4.1(24)
B3	2.4(1)	2.4(4)	.....	3.7(7)	3.4(4)	4.0(9)	4.8(13)	3.9(38)
Total	3.1(3)	2.8(6)	4.3(4)	3.6(17)	3.4(12)	4.4(22)	4.5(15)	3.9(79)

REGION: CEPHEUS; α $20^h48^m-22^h15^m$; δ $+54°$ to $+64°$

Spectrum	Magnitude							
	4.5	5.5	6.5	7.5	8.5	9.5	10.5	Total
O	.....	6.0(3)	.....	.....	3.3(1)	.....	.....	5.4(4)
Bo	.....	4.3(3)	5.7(5)	3.2(2)	.....	.....	.....	4.8(10)
B1	.....	.....	4.8(1)	.....	.....	.....	.....	4.8(1)
B2	7.0(1)	5.4(3)	.....	5.2(2)	.....	.....	.....	5.6(6)
B3	.....	2.0(2)	5.3(6)	5.8(5)	.....	.....	.....	5.0(13)
Total	7.0(1)	4.7(11)	5.4(12)	5.1(9)	3.3(1)	.....	.....	5.1(34)

NOTE.—The positions given for each region are only approximate. They serve for identification. The numbers of stars are given in parentheses.

In whichever way the stars are grouped they differ comparatively little from the mean value for the whole cluster. This mean value, however, may be as low as 2.1 (for the Orion-nebula group) and as high as 5.1 (for the Cepheus group). We are here dealing with the "regional effect" discussed in the preceding paragraph.

In two or three cases there seem to be indications that the fainter magnitudes are associated with stronger lines, but this is contradicted in other cases. The effect, if real, may be caused by stars of the foreground or the background, and I do not believe that at the present stage of this work there is need for a hypothesis demanding stronger lines for smaller luminosities.

In most regions the O stars exhibit a slight tendency toward stronger lines than the later types. But in Orion the reverse is true, and in Cygnus and Sagittarius the effect is not noticeable. The possibility cannot be denied that earlier types may be associated with slightly stronger lines, independently of the effect of distance.

IX. THE O STARS

Although the material is small I have divided the O stars according to subtype. The results are shown in Table XV.

TABLE XV

INTENSITIES OF DETACHED K IN O STARS

Spectrum	No.	Average Intensity
P Cygni type	8	7.5
Oa	10	3.6
Ob	7	2.6
Oc	5	5.4
Od	3	4.0
Oe	12	4.8
Oe5	48	4.2

The P Cygni stars are included because P Cygni itself is classified as B1p in the *Henry Draper Catalogue*. According to the measures of one plate by Professor Edwin B. Frost,[1] the velocity from K nearly agrees with the reflex of the solar motion, while the other absorption lines give very different values. Frost is led to the conclusion: ". . . . it yielded a velocity of 0 km, thus differing widely from the dark silicon lines. Such behavior of the K line is found so frequently in spectra of type B that it is hardly abnormal, although as yet unexplained." R. H. Curtiss[2] obtained -17 ± 1.6 km/sec. for

[1] *Astrophysical Journal*, **35**, 293, 1912.

[2] *Popular Astronomy*, **22**, 133, 1914.

K, and a similar value was obtained by C. T. Elvey.[1] P. W. Merrill[2] has measured K in the P Cygni star D.M.+10°4673, but the difference between this line and the others is small, and so constitutes an uncertainty.

X. STARS WITH BRIGHT HYDROGEN LINES

Among the 1718 stars investigated here there are 96 which are mentioned in the remarks to the *Henry Draper Catalogue* as having bright hydrogen lines. According to B. P. Gerasimovič[3] and R. H. Curtiss,[4] these stars are more luminous than the ordinary B's. There

TABLE XVI

INTENSITIES IN Be STARS

MAG.	SLIT SPECTROGRAMS				THE WHOLE MATERIAL			
	No.	*I*(Be)	No.	*I*(B)	No.	*I*(Be)	No.	*I*(B)
0– 1	0	.....	0	.....	0	.....	1	1.0
1– 2	0	.....	7	1.8	0	.....	10	1.0
2– 3	3	1.2	14	1.8	4	1.8	28	1.3
3– 4	3	1.2	19	2.8	6	1.2	36	2.0
4– 5	14	4.0	65	2.6	18	2.6	123	2.4
5– 6	9	3.5	79	3.1	17	3.1	188	2.9
6– 7	12	4.9	50	3.2	23	3.0	293	3.1
7– 8	11	4.0	25	3.7	18	3.8	371	3.5
8– 9	3	2.7	4	5.0	8	4.7	364	3.7
9–10	1	2.0	2	3.0	2	4.8	180	4.0
10–11	0	.....	0	.....	0	.....	28	4.5
Total	56	3.7	265	3.0	96	3.1	1622	3.3

is also evidence that they are redder in color than the stars without hydrogen emission.[3] I have grouped the material for the slit spectrograms separately from the rest.

The results are at first a little confusing. If we consider only the arrangement by magnitudes (Table XVI), we find a small but rather persistent predominance for the Be stars. This is especially pronounced for the whole material.

In the arrangement by spectral types (Table XVII) the effect clearly persists in the slit spectrograms, but it is not noticeable for

[1] Private letter.

[2] *Publications of the Detroit Observatory*, **2**, 71, 1916.

[3] *Harvard College Observatory Bulletin*, No. 849, p. 8, 1927.

[4] *Journal of the Royal Astronomical Society of Canada*, **20**, 35, 1926.

the whole material, and the mean of all Be intensities, 3.1, is slightly less than for the B's, 3.3. This apparent contradiction is explained by the difference in the frequency distribution according to apparent magnitude. The Be stars show maximum frequency for much brighter magnitudes than the B's. Consequently, if the stars are arranged by spectral types, the proportion of faint stars is greater for the B's than for the Be's. This will cause an unequal distribution in the intensities, because of the effect of apparent magnitude, discussed under head V. Since the lines are stronger in faint stars,

TABLE XVII

INTENSITIES IN Be STARS ARRANGED ACCORDING TO SPECTRAL TYPE

Spectrum	Slit Spectrograms				The Whole Material			
	No.	*I*	No.	*I*	No.	*I*	No.	*I*
O	4	5.8	22	4.1	6	5.2	89	4.4
Bo	13	3.8	30	3.5	18	3.5	284	3.7
B1	5	3.6	22	2.9	5	3.9	61	3.1
B2	11	4.8	40	4.0	26	3.2	300	3.7
B3	23	2.8	151	2.4	41	2.5	888	3.0
Total	56	3.7	265	3.0	96	3.1	1622	3.3

it is obvious that a group of stars containing more faint stars than another one will show stronger lines, on the average.

Whether the difference in the modes of the two frequency distributions is real or whether it is merely a result of selection (probability of discovery) can hardly be decided at present. But it is significant that it agrees in sign and even in size with the value given by Gerasimovič for the difference in absolute magnitudes:

$$M(\mathrm{B3e}) - M(\mathrm{B3}) = 2.4 \pm 1.1 \ .$$

From Table XVI, I find:

Maximum frequency for Be at apparent mag.	6.5
Maximum frequency for B at apparent mag.	8.0
Difference	1.5

Summarizing these results we may say that it appears highly probable that the Be stars have stronger detached lines than the

ordinary B's. Since the Be's are more luminous than the B's this can be interpreted in the light of a distance effect.

XI. THE STELLAR CALCIUM LINES

In Table X, I have given the mean intensities of the detached and stellar calcium lines for different spectral subdivisions. At no point in the spectral sequence do the lines disappear, and there is certain to be a mixture of both types of lines in subdivision B_3 and perhaps also B_5. Probably the detached lines predominate in B_3, and the stellar in B_5.

TABLE XVIII

FREQUENCY DISTRIBUTION OF CALCIUM INTENSITIES IN LATER SPECTRAL TYPES

0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–	Total
B5												
15	27	31	41	15	6	7	0	4	1	0	3	150
B8												
5	5	14	15	9	5	5	2	1	0	0	2	63
B9												
0	5	6	5	8	7	3	1	4	0	1	1	41
A0												
0	1	3	3	5	6	3	4	10	4	8	12	59
A2–A3												
0	0	0	0	0	1	2	0	1	1	1	19	25

It is of interest to see whether and to what extent stellar calcium lines can penetrate into the domain occupied by the detached lines (O–B_3). Table XVIII gives the observed frequencies for the later spectral subdivisions.

Figure 3 shows the most probable course of the intensities for the stellar calcium line. We may regard this curve as the central line of a frequency distribution, marking the highest frequencies for

each spectral subdivision. The observed dispersions for types B8, B9, and A0, which are not affected by the detached absorption, are:

	Units
For B8:	$\sigma = \pm 2.5$
For B9:	$\sigma = 2.5$
For A0:	$\sigma = \pm 4.6$

These values are affected by the uncertainty of measurement $\sigma_\epsilon = \pm 1.2$. The cosmic dispersion σ_c computed from the formula

$$\sigma_c = \pm \sqrt{\sigma^2 - \sigma_\epsilon^2}$$

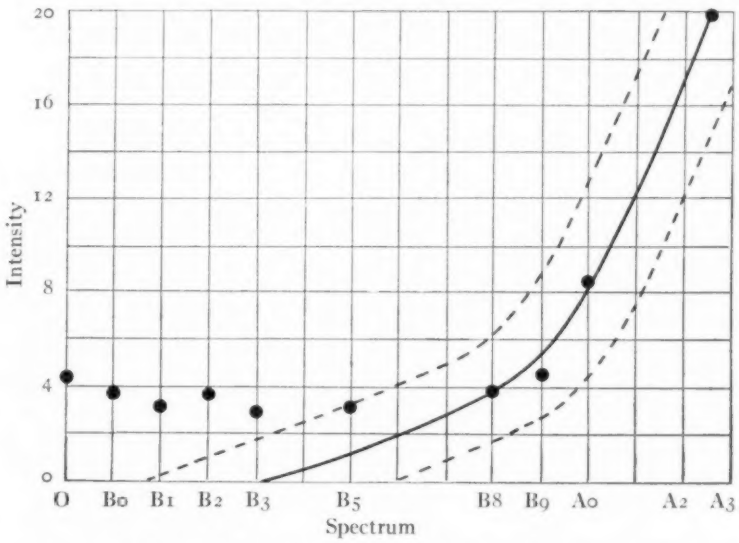

FIG. 3.—Calcium intensities for various spectral subdivisions. Black dots represent the observed intensities. The continuous line shows the course of the intensities of the stellar lines, observed between A3 and B8, and extrapolated from B8 to the left of the diagram. The dotted lines show the range of the standard deviation, also extrapolated from B8 to the left.

amounts to ± 2.2, ± 2.2, and ± 4.2 units for the three spectral types, respectively.

The physical meaning of this dispersion does not interest us here. Doubtless it is due to the fact that the various standards on which Miss Cannon's classification is based are not quite homogeneous. The intensity of K is one of her standards, but this may not always

exactly agree with the required intensities from the helium and other lines (perhaps as a result of unequal relative abundance in different stars). The dotted curves in Figure 3 mark the respective standard deviations. Assuming a Gaussian distribution for the intensities, which is sufficiently close in this case, they indicate that one-quarter of all stars of a given type lie above the upper dotted line, while one-quarter fall below the lower line. Extrapolating the lines toward the earlier types, we can estimate the relative number of stars of a given subdivision that will show stellar calcium lines of an appreciable strength. It would appear from the diagram that at B3 still one-half of all stars have stellar lines stronger than intensity 0, while at B1 the proportion is one-quarter. Even at B0 there will be found a small percentage of stars with faint stellar lines.

The existence of stellar lines in early types is thus not only possible but almost inevitable. The result is undoubtedly an effect of blending of a stellar line with one of the detached type, and this explains satisfactorily most cases of spectroscopic binaries showing calcium lines oscillating with the same period but with a smaller amplitude than the stellar lines. This is in good agreement with B. J. Bok's[1] result that the number of binaries showing oscillating calcium lines decreases as we proceed from the later to the earlier types. If Bok's list is brought up to date, and if a few stars, such as 12 Lacertae,[2] are omitted, the agreement becomes even better.

XII. DISCREPANT STARS

There remain, however, several cases of spectroscopic binaries for which the blend hypothesis fails. These may be divided into two groups:

1. Stars having large amplitudes for the stellar lines. Such binaries should show no blending near maximum relative velocity, since the stellar line would be sufficiently far removed from its normal position to avoid any interference with the detached line. The most outstanding cases of this nature, taken from Bok's list, are β Scorpii and ψ Orionis.

[1] *Bulletin of the Astronomical Institutes of the Netherlands*, **4**, 9, 1927.

[2] R. K. Young, *Journal of the Royal Astronomical Society of Canada*, **19**, 46, 1925; W. H. Christie, *Publications of the Dominion Astrophysical Observatory, Victoria*, **3**, 215, 1925.

2. Three binaries the orbits of which were derived from the detached lines only (9 Camelopardalis, ξ Persei, and χ Aurigae).

With regard to the first group, I believe that recent evidence is against their reality. Pearce[1] has shown that Boss 46 has perfectly "stationary" calcium lines. ψ Orionis has been mentioned by R. K. Young[2] as a case where the semi-amplitude of the stellar lines is 144 km/sec., while that of the detached lines is 80 km/sec. The spectral

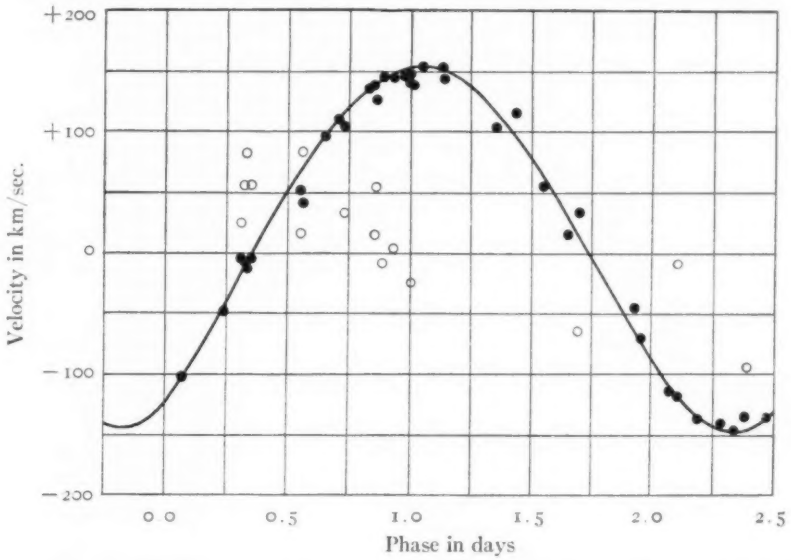

FIG. 4.—Velocity-curve of the spectroscopic binary ψ Orionis. The points indicate J. S. Plaskett's velocities for the brighter component of this system. Harper's measures of the calcium lines are shown by circles.

type is B2. The orbit was derived by J. S. Plaskett[3] without reference to the calcium lines. These were later measured by W. E. Harper.[4] In Figure 4 I have plotted his values together with Plaskett's velocity-curve. It is evident that K does not oscillate with a velocity-curve similar to that of the stellar lines. The diagram seems to indicate that detached K is blended with the stellar line for a

[1] *Publications of the Dominion Astrophysical Observatory, Victoria*, **3**, 275, 1926.

[2] *Op. cit.*, **1**, 220, 1920.

[3] *Astrophysical Journal*, **28**, 266, 1908.

[4] *Publications of the Dominion Observatory, Ottawa*, **4**, 343, 1919.

short time near γ-velocity, after which it is completely separated. I would consider this plot rather a support for the blend hypothesis.

Nine additional plates were obtained at the Yerkes Observatory during the winter of 1927–1928, and are shown plotted in Figure 5. Again there is apparently no real oscillation for the detached lines. The calcium lines in this star are faint and difficult to measure, so that large errors may be expected.

In the case of β Scorpii the evidence is divided. Z. Daniel and F. Schlesinger[1] suspected a small oscillation. At the same time J. C.

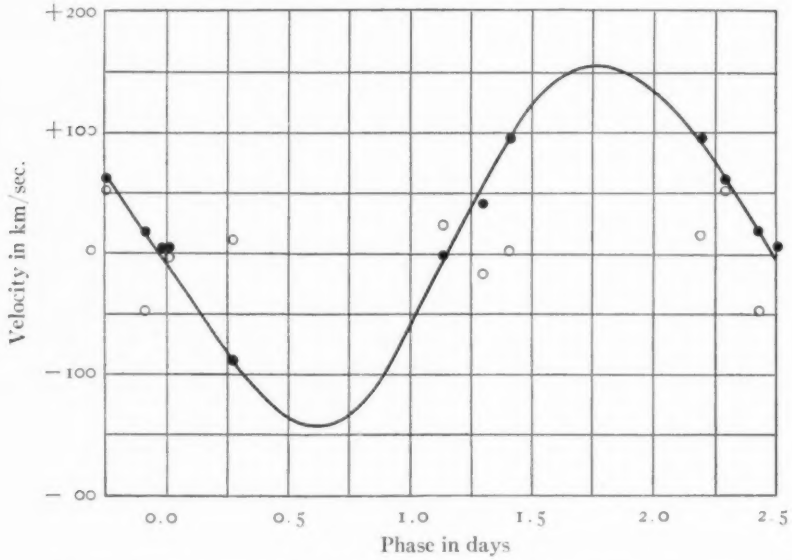

FIG. 5.—Velocity-curve of ψ Orionis from Yerkes spectrograms (1927–1928). The velocity of the star is shown by points. The calcium velocities are shown by circles.

Duncan[2] found no variation in the velocity of K. This case must, therefore, be regarded as uncertain.

The three stars of the second group are more difficult to explain. In al cases the range in velocity is small (K = 8 km/sec. for ξ Persei; K = 9 km/sec. for 9 Camelopardalis, and K = 21 km/sec. for χ Aurigae). Additional observations will be required before their exact nature can be determined. In the case of 9 Camelopardalis the stellar

[1] *Publications of the Allegheny Observatory*, **2**, 135, 1912.

[2] *Lowell Observatory Bulletin*, **2**, 21, 1912.

lines show fairly large deviations but no satisfactory velocity-curve could be construed. The possibility of blends is not quite ruled out.

There is at present no definite proof against the blend hypothesis for oscillating detached lines.

XIII. PROPOSED HYPOTHESIS

It seems to me that without stressing the results of the preceding paragraphs unduly we may assume that the intensity of a detached line depends chiefly upon the distance of the star. This would explain qualitatively the observed relation of intensity to apparent magnitude and to spectral type.

In my previous paper I have shown that "calcium clouds" have nothing in common with dark or bright nebulae. This at once suggests that we should think rather of a "cloud in space" (to use Eddington's words) than of many separate clouds. Regional effects would then be the result of the well-known tendency of B-type stars to form clusters. The relative intensity of the detached lines for each such cluster would depend on its distance from the sun.[1]

The only serious objection that I can see to this idea is that the observed calcium velocities differ in some cases appreciably from the reflex of the solar motion. It is true that the motion of the solar system with respect to the calcium masses is subject to some uncertainty. There may also exist blend effects due to the presence of stellar lines. Nevertheless, it is probable that some of the residual velocities are real.[2] In that case we must think of some sort of a diffuse cloud similar in structure and in motions to the Orion nebula, but vastly larger. Peculiar motions will then be observed, and there may occur condensations in the general cloud. But just as Hubble

[1] This possibility was discussed in my previous paper (p. 12). It was shown that for Cepheus the brighter stars, alone, show an intensity considerably in excess of those in Orion having the same average apparent magnitude. This could be construed as a proof against uniform distribution of calcium atoms in space. It does not, however, affect the statistical correctness of our hypothesis. Nor is it impossible that the average absolute magnitude of the stars in Cepheus differs from that in Orion.

[2] It should be noted that the rotation of the galaxy advocated by J. H. Oort (*Bulletin of the Astr. Inst. of the Netherlands*, **3**, 275, 1927; **4**, 79, 1927; **4**, 91, 1927) and recently confirmed by J. S. Plaskett (*Journal of the Royal Astronomical Society of Canada*, **22**, 131, 1928) would satisfactorily explain at least part of these peculiar velocities. A more detailed discussion will be given in another paper.

was able to trace the inverse-square law in the distribution of brightness of the diffuse galactic nebulae, we may be able to observe the "distance effect" in the intensities of the detached lines.

Another objection to which I called attention in my previous paper is the absence of detached lines in later types. The combination of great distance and large velocity-displacement for the stellar lines is a condition for the possibility of observing detached lines. This condition is fulfilled in very few stars observable with modern slit spectrographs,[1] and the fact that up to the present no such lines have been found cannot, perhaps, be regarded as sufficient reason for discarding the proposed hypothesis. Additional observational material on stars likely to show detached lines will doubtless settle this point before long.

For the present, we shall neglect all other causes that may affect the intensity of detached K. We then obtain a simple relation between the intensity I and the distance D:

$$I = f(D) .$$

Eddington's theory would enable us to predict the foregoing relationship, provided that the distribution of calcium atoms in the stellar universe is known. For the central parts a uniform distribution may be supposed, and Eddington has made use of this as-

[1] There is one group of stars, however, where both conditions are fulfilled. In the spectra of the novae the ordinary stellar lines are displaced many angstroms to the violet. At the same time their distances are believed to be very large (Lundmark, various articles in *Publications of the Astronomical Society of the Pacific*). In all these stars there have been observed the narrow detached lines of calcium and of sodium. It is remarkable, furthermore, that in spite of the tremendous changes in spectral type and luminosity of the novae, the intensity of detached K remains practically constant. I have examined from this point of view the spectra of three novae photographed at the Yerkes Observatory. For Nova Aquilae 1918 I find from a large number of plates that the intensity of detached K was about 3.5 between June 9 and August 12. For Nova Cygni 1920 it was 6.5 between August 23 and September 13, and for Nova Geminorum 1912 it was 6.5 between March 15 and April 2. This remarkable stability in intensity is a strong argument in favor of the hypothesis of interstellar calcium. It is true that for Nova Geminorum 1912, R. H. Curtiss has found a decline in the velocity from the detached lines amounting to 7 km/sec. This effect was absent, however, in Nova Aquilae and Nova Cygni (*Popular Astronomy*, **33**, 167, 1925). Curtiss suggests radiation pressure as an explanation. The fact, however, that the total change in velocity did not exceed 7 km/sec. indicates that the calcium atoms must have been very far from the star.

sumption. But since many of our stars lie thousands of parsecs from the sun, such a supposition may not be justified.[1]

We shall, therefore, derive our relationship empirically. After it has once been established, it will also serve for deriving distances when the intensities are known. There will be a certain amount of scattering around the central curve. This will be due in part to errors in the estimated intensities, and in part to other causes affecting the intensities, which we have decided to neglect.

Unfortunately, our material for calibrating equation $I = f(D)$ is very scarce.

1. We shall assume, with Eddington,[2] that the spectroscopic binary 66 Eridani is at a distance of 100 parsecs and does not show any detached lines.

2. The Orion-nebula group, for which we had an average intensity of 2.1, has been found by various investigators to lie at a distance of about 180 parsecs.[3]

3. For the cluster in Perseus we have an intensity of 4.0. R. Trumpler[4] finds $D = 2300$ parsecs. The determinations of various investigators vary greatly, but the foregoing value is probably the most trustworthy of all.

4. For the cluster in Cygnus my estimate of the distance[5] is about 1000 parsecs. The observed intensity is 3.9.

5. For the absorption O stars (Harvard Oe5 and Oe) an average absolute magnitude of -4.0 is adopted.[6] The observed data are:

Oe: 12 stars; aver. int. 4.8; aver. appar. mag. 7.2; $D = 1730$
Oe5: 48 stars; aver. int. 4.2; aver. appar. mag. 6.8; $D = 1450$

[1] Eddington (*Proceedings of the Royal Society of London*, A, **111**, 428, 1926) also remarks that his computations of the density of interstellar matter refer to the central parts of the galactic system and that at the confines of the system the density will probably fade out.

[2] *Ibid.*, p. 445, 1926.

[3] J. C. Kapteyn, *Contributions from the Mount Wilson Observatory*, No. 147, 1918; *Astrophysical Journal*, **47**, 104, 146, 255, 1918; N. H. Rasmuson, *Meddelanden från Lunds Astronomiska Observatorium*, Ser. II, No. 26, 1921; Ö. Bergstrand, *Sur le groupe des étoiles a helium dans la constellation d'Orion*, Stockholm, 1919.

[4] *Publications of the Astronomical Society of the Pacific*, **38**, 352, 1926.

[5] *Astronomische Nachrichten*, **231**, 38, 1927.

[6] Russell, Dugan, and Stewart, *Astronomy*, **2**, 667, 1927.

6. For the P Cygni stars the average absolute magnitude, as derived from the Magellanic Clouds, is -6.[1] I shall adopt here a slightly smaller value, namely, -5.5, since the average absolute magnitude of the O stars in the Magellanic Cloud (-5) is also slightly more luminous than the value applicable for our stellar system (-4). The average intensity is 7.5. The average apparent magnitude is 8.5 and consequently $D = 6500$ parsecs.

The relationship between distance and intensity of K is given in Figure 6. In spite of the great uncertainty of this curve, there can be but little doubt that it is substantially correct.

XIV. SOME CONSEQUENCES

a) *Absolute magnitudes of helium stars.*—Under head V it was found that the intensity of detached K increases by 0.4 unit per magnitude. This enables us to establish approximate absolute magnitudes for different spectral types, provided that the magnitude of one subdivision is known. We shall adopt $M(B_3) = -1.0$.

TABLE XIX

ABSOLUTE MAGNITUDES OF HELIUM STARS

Spectrum	*I*	Absolute Magnitude	Remarks
O	4.4	−4.5	
Bo	3.7	2.8	
B1	3.1	1.3	
B2	3.6	2.5	
B3	3.0	−1.0	Assumed

The values in Table XIX agree satisfactorily with other determinations.[2]

b) *Distribution of interstellar calcium.*—In my former paper I have given the following approximate calibration of my arbitrary scale:

Estimate	1	2	3	4	5	6	7	8	9	10
Mag. diff	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

Every unit corresponds to 0.1 stellar mag.

[1] *Ibid.*, p. 803.

[2] It should be noted that these absolute magnitudes are independent of the curve in Fig. 6. Their agreement with data obtained by other methods constitutes another argument in favor of our hypothesis.

If we assume uniform distribution of the calcium atoms all over space, we should get the intensity of the dimmed light I to the undimmed I_0 by the following expression:

$$I = I_0 e^{-\beta x} ,$$

where β is the absorption coefficient and x the thickness of the absorbing layer. What we actually observe is the value $(m - m_0)$, name-

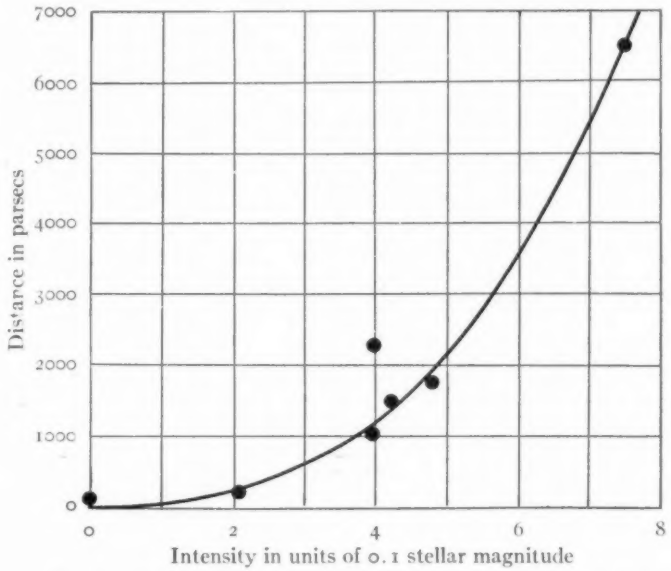

FIG. 6.—Relationship between intensity of detached K and distance

ly, the difference between the intensity of the continuous spectrum m and that in the line, m_0, both expressed in stellar magnitudes:

$$m - m_0 = 2.5 \log I/I_0 .$$

If I_0 is put equal to 1, we get:

$$m - m_0 = \text{Const. } x .$$

In other words, the observed intensities should be proportional to the distances. Figure 6 suggests that this is not the case. It is impossible to join all points by drawing a straight line through the origin. The departure from a straight line is in the sense of a de-

creasing density of the calcium atoms as we approach the limits of the galactic system.[1] Unfortunately, the uncertainty of the curve, as well as of the calibration of my intensities, is such that it would be useless to evaluate the law of distribution of the calcium atoms.

c) Average distances and absolute magnitudes of certain groups of stars.—With the use of the smoothed curve in Figure 6 it is possible

TABLE XX

DISTANCES OF CERTAIN GROUPS OF STARS

Region	Aver. Int.	*D* (in Parsecs)
Cygnus	3.9	1400
Carina	3.6	1100
Crux	3.7	1200
Scorpius	4.3	1800
Sagittarius	3.4	1000
Monoceros	4.3	1800
Orion	2.1	200
Perseus	4.0	1400
Cepheus	5.1	2800

TABLE XXI

ABSOLUTE MAGNITUDES OF WOLF-RAYET STARS

Spectrum	Aver. Int.	*D*	Aver. Appar. Mag.	*M*
Oa	3.6	1100	7.1	−3.1
Ob	2.6	500	8.2	0.3
Oc	5.4	3300	7.2	0.4
Od	4.0	1400	4.7	−6.0

to derive approximate distances of the various groups of stars discussed under head VIII.

In a similar way we obtain for the various classes of Wolf-Rayet stars the data shown in Table XXI.

With the exception of Od, which approaches the P Cygni stars in absolute magnitude, all other Wolf-Rayet stars are absolutely much fainter than the ordinary absorption O stars.

B. P. Gerasimovič has suggested, independently,[2] that the Wolf-

[1] This conclusion depends entirely upon the assumed distance of the P Cygni stars. In a forthcoming publication by Gerasimovič and the writer this question will be rediscussed.

[2] Private communication.

Rayet stars form a transition between the ordinary O stars and the planetary nebulae.[1] The central stars of the latter are known to be about 5 mag. fainter than the O's; which would give for them $M = +1$.

XV. CONCLUSIONS

In a general way this work tends to confirm my former investigation. The chief observational results may be summarized as follows: (1) Fainter stars have stronger detached lines than brighter ones. The increase in the intensity of K amounts to $0^{M}4$ per magnitude. (2) The earlier spectral subdivisions (O–B3) have stronger lines than the later ones. (3) Several physical groups of stars show well-defined average intensities, but give no certain evidence as to any relationship between luminosity and intensity of K. (4) Be stars have probably slightly stronger detached lines than ordinary B's. (5) Spectroscopic binaries showing oscillating calcium lines may be interpreted as a blending of a stellar and a detached line.

The chief obstacles in the way of Eddington's suggested hypothesis have been removed in the present study: (1) There is no decline in the intensity of K for the faintest stars. (2) Spectroscopic binaries with oscillating K lines constitute no proof to the contrary.

There still remain two major objections: (1) The non-occurrence of detached lines in spectral types later than B3. Further work will have to be undertaken to see whether this is actually the case. (2) The existence of peculiar radial velocities from the detached calcium lines. This, if real, would be contrary to the idea of a uniform cloud of calcium atoms, but it does not necessarily contradict the hypothesis of Eddington. There may exist in the general cloud condensations showing peculiar motions, similar to those observed in the Orion nebula.

In view of the increasing evidence in favor of the hypothesis of Eddington, I have suggested that we put $I = f(D)$, thus neglecting all other factors that may determine the intensity of K (such as non-uniformity in the distribution of calcium atoms). It should be noted that this assumption, while predicted from Eddington's hy-

[1] C. Wirtz has also recently called attention to the fact that the Wolf-Rayet stars (Oa, Ob, Oc) are about 3 mag. fainter than the other O stars (Od, Oe, Oe5) (Müller-Pouillet, *Lehrbuch der Physik* [11. Auflage], **5**, Part 2, 230 and 264).

pothesis, does not rest on it. It is derived empirically from the relation between intensity and apparent magnitude, and is evaluated graphically from certain groups of stars the average distances of which were supposed to be known. The uncertainty of the curve is very great, but the fact that consistent results are obtained for the absolute magnitudes of certain groups of stars lends some plausibility to the assumption. The relation $I=f(D)$ holds statistically. The material is insufficient, however, to determine the scattering from it of individual values.

Our final conclusion would then be that present observational evidence does not contradict Eddington's theoretical ideas, but in some respects even favors them. Caution must, of course, be exercised as long as the objections mentioned above have not been submitted to a careful scrutiny. It would also be desirable to repeat all or part of the work using only one series of plates. For this purpose it would be best to utilize one of the smaller dispersions (for example, that of series I) and to secure additional plates of the brighter stars, timed in such a way as to make the photographic density comparable to that of the faint stars on long exposures. I believe, however, that the consistency of the results submitted here, and their general agreement with information derived from slit spectrograms, is a sufficient guaranty that no changes in the conclusions will be caused by such a revision.

I am greatly indebted to Director Harlow Shapley for the opportunity to take up this study at the Harvard College Observatory. Many thanks are also due to Miss Cannon for the use of her original notebooks, without which it would have been impossible to accumulate such a large amount of material. I am indebted also to Miss Payne and to Professor Gerasimovič, for access to unpublished material. Dr. A. Pogo assisted in the drawing of Figure 2. Most of the computations involved in this paper were made by Mme L. Struve and by Miss L. D. Cable.

YERKES OBSERVATORY
UNIVERSITY OF CHICAGO
February 15, 1928

IDENTIFICATION OF LINES IN THE SPECTRUM OF η CARINAE[1]

By PAUL W. MERRILL

ABSTRACT

The spectrum of η Carinae consists essentially of *emission lines*, among which those of *hydrogen* and *ionized iron* have long been recognized. A few other lines are probably due to ionized titanium and ionized chromium.

This paper identifies most of the remaining lines with *forbidden lines arising from metastable states of the ionized-iron atom*. Low density is thought to be the condition which allows these non-laboratory lines to occur. Two curious instances of *violations of the inner-quantum-number rules* are noted.

The spectrum of the remarkable southern variable star η Carinae,[2] consisting chiefly of numerous emission lines, is a most unusual one. Lines due to hydrogen and ionized iron are readily recognized, and a few of the fainter remaining ones may be ascribed to ionized titanium and ionized chromium. Although the spectrum has been known for many years through the observations of the Harvard College Observatory,[3] and those of Gill,[4] of Moore and Sanford,[5] and of Lunt,[6] a number of the strongest lines have nevertheless remained unidentified. Several of the unknown lines have been observed in the spectra of novae and, recently, in a few other peculiar stars.

The lines measured by Moore and Sanford and by Lunt are listed in Table I. The wave-lengths have been converted to the international system. In addition, a correction of -0.17 A has been

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 354.

[2] H.D. 93308; R.A., $10^h41^m.2$; Dec., $-59°10'$ (1900). Remark in *Henry Draper Catalogue:* "Nova Carinae, No. 1. The star was of the fourth magnitude at the time of the first recorded observation in 1677. In 1751, it was of the second magnitude, and from 1837 to 1854, it was about mag. 0.3. In 1869, it had declined to the seventh magnitude, and has fluctuated between the seventh and eighth magnitudes since that time."

[3] *Harvard Annals*, **28**, 175, 1897; **76**, 36, 1916.

[4] *Monthly Notices, R.A.S.*, **61**, Appendix, p. 66, 1901.

[5] *Lick Observatory Bulletins*, **8**, 55, 1913.

[6] *Monthly Notices, R.A.S.*, **79**, 621, 1919.

TABLE I

BRIGHT LINES IN THE SPECTRUM OF η CARINAE

LUNT		MOORE AND SANFORD			IDENTIFICATION
I.A.	Int.	I.A.		Int.	
		1913	1912		
4068.56	00	.....	.....	.....	68.62 *Neb.* ??
Hδ	0	*Hδ*	*Hδ*	0	*Hδ*
4122.87	000	.....	.....	.....	22.67 *Fe* II
4143.00	000	.....	.....	.....	.....
4171.65	000	.....	.....	.....	71.91 *Ti* II
4173.33	0	73.50	.....	1	73.48 *Fe* II
4178.07	1	77.39	.....	0	77.22 [*Fe* II]
		78.75	.....	1	78.87 *Fe* II
4200.91	00	.....	.....	.....	99.87 *He* II?
4233.03	5	33.14	33.24	5	33.16 *Fe* II
4243.77	8	44.09	43.95	8	43.97 [*Fe* II]
.....	.....	45.35	.....	1	44.85 [*Fe* II]
4258.25	00	.....	.....	.....	58.16 *Fe* II
.....	.....	73.63	.....	0—	73.31 *Fe* II
4276.74	4	76.86	.....	5	76.87 [*Fe* II]
4287.31	9	87.30	87.28	10	87.40 [*Fe* II]
.....	.....	89.73	.....	2	90.23 *Ti* II
4296.66	0	96.71	.....	0	96.56 *Fe* II
4303.30	1	99.62	.....	0	00.05 *Ti* II
		03.07	.....	1	03.18 *Fe* II
		05.76	.....	1	05.90 [*Fe* II]
4313.25	00	.....	.....	.....	12.88 *Ti* II?, 14.98 *Ti* II??
4319.69	2	19.54	.....	2	19.64 [*Fe* II]
.....	.....	24.48	.....	0—	.....
.....	.....	26.72	.....	0—	.....
4330.26	00	30.03	.....	0—	.....
4336.96	1	.....	.....	.....	37.92 *Ti* II
Hγ	3, 6	*Hγ*	*Hγ*	5, 4	*Hγ*
4346.75	1	46.61	.....	1	46.87 [*Fe* II]
4352.09	7	52.10	51.78	8	51.77 *Fe* II, 52.80 [*Fe* II]
4359.26	10	58.95	58.79	10	59.34 [*Fe* II], 58.38 [*Fe* II]
4362.21	2	61.35	.....	2	.....
4369.43	000	.....	.....	.....	69.41 *Fe* II
4372.41	1	72.56	.....	0	72.46 [*Fe* II]
4382.34	0	.....	.....	.....	82.76 [*Fe* II]
4385.71	1.5	85.33	.....	2	85.39 *Fe* II
4394.47	0	94.68	.....	0—	95.04 *Ti* II
4399.06	00	.....	.....	.....	99.77 *Ti* II
4403.86	000	.....	.....	.....	.....
4411.05	000	.....	.....	.....	.....
4413.72	8	13.88	13.56	8	13.79 [*Fe* II]
4416.48	9	16.27	16.11	9	16.28 [*Fe* II], 16.81 *Fe* II
4419.11	0	.....	.....	.....	.....
4421.36	000	.....	.....	.....	.....
4426.59	000	.....	.....	.....	.....
4443.10	0	42.83	.....	0	43.80 *Ti* II
4448.05(?)	000	.....	.....	.....	.....

TABLE I—*Continued*

Lunt		Moore and Sanford			Identification
I.A.	Int.	I.A.		Int.	
		1913	1912		
4452.09	4	51.95	51.71	6	52.09 [*Fe* II]
.....	.....	54.94	.....	0	.....
4457.99	3	57.81	57.37	5	57.96 [*Fe* II]
4460.96	00	.....	.....	.....	.....
4468.21	00	67.94	.....	0	68.49 *Ti* II
4474.75	2	74.71	.....	3	74.90 [*Fe* II]
4488.81	4	89.05	.....	3	89.21 *Fe* II, 88.77 [*Fe* II]
4491.83	5	91.59	91.55	3	91.41 *Fe* II, 92.65 [*Fe* II]?
4500.54	0	00.44	.....	0	01.27 *Ti* II
4508.25	5	08.39	08.51	5	08.29 *Fe* II
4515.08	5	15.29	15.52	5	15.34 *Fe* II, 14.92 [*Fe* II]?
4519.97	4	20.32	.....	3	20.24 *Fe* II
4522.62	6	22.55	22.04	5	22.64 *Fe* II
4533.77	2	33.70	.....	2	34.17 *Fe* II, 33.97 *Ti* II
4541.58	1	41.61	.....	0	41.52 *Fe* II, 41.63 *He* II?
4549.49	7	49.33	49.33	7	49.48 *Fe* II, 49.64 *Ti* II
4555.55	6	55.69	55.59	4	55.90 *Fe* II
4559.30	3	58.39	.....	2	58.66 *Cr* II
4563.36	1	63.42	.....	1	63.77 *Ti* II
4571.06	2	71.33	.....	2	71.98 *Ti* II
4576.38	2	76.57	.....	2	76.31 *Fe* II
4580.36	1	.....	.....	.....	.....
4583.97	9	83.84	83.74	9	83.84 *Fe* II
4587.86	3	88.03	.....	3	88.21 *Cr* II
.....	.....	89.86	.....	2	.....
4616.57	000	16.42	.....	0	16.67 *Cr* II
4619.36	2	20.05	.....	0	18.85 *Cr* II, 20.52 *Fe* II?
4629.53	7	29.31	29.29	8	29.33 *Fe* II
4634.74	1	34.49	.....	0	35.32 *Fe* II, 34.08 *Cr* II
4637.52	000	.....	.....	.....	.....
4639.62	2	39.66	.....	2	39.69 [*Fe* II]
4657.02	00	57.25	.....	0−	56.98 *Fe* II
4663.85	00	63.87	.....	0	63.71 *Fe* II
4666.99	00	66.87	.....	1	66.75 *Fe* II
.....	.....	68.61	.....	0	.....
4727.92	5	28.17	.....	5	28.09 [*Fe* II]
4731.81	1	31.45	.....	2	31.49 *Fe* II
4774.60	0	74.63	.....	0	74.74 [*Fe* II]
4814.40	5	14.60	14.68	5	14.55 [*Fe* II]
4824.12	00	24.46	.....	0+	24.13 *Cr* II
4848.37	00	48.03	.....	0	48.27 *Cr* II
Hβ	.....	*Hβ*	*Hβ*	30	*Hβ*
4874.64	0	75.01	.....	0	74.54 [*Fe* II]
4889.54	0	89.46	.....	3	89.66 [*Fe* II]
4905.25	000	05.62	.....	0	05.37 [*Fe* II]
4923.94	5	23.96	23.99	8	23.92 *Fe* II
5018.85	(0)	18.60	17.97	5	18.44 *Fe* II
51	.....	59.5	.....	1−	.....
51	.....	69.1	.....	1	69.03 *Fe* II

applied to the 1912 wave-lengths of Moore and Sanford to make them homogeneous with the 1913 results. The probable identifications are given in the last column. Those for *Fe* II, *Ti* II, and *Cr* II agree in general with the assignments by previous investigators, but new data have made it possible to include additional lines. Many of the remaining lines, including some of the strongest in the whole spectrum, appear to be "forbidden" lines of the ionized-iron spectrum, not observed in the laboratory but calculable from known terms. Such lines are indicated by square brackets, e.g., [*Fe* II].

It is interesting to note how completely the ordinary lines of *Fe* II are present. Even the weak lines not observed in the laboratory, but

TABLE II

DISPLACEMENTS OF LINES

	LUNT		MOORE AND SANFORD	
	Δλ	No.	Δλ	No.
Fe II	+0.05A	22	−0.01A	22
[*Fe* II]	− .09	18	− .03	20
Ti II	− .62	9	− .58	8
Cr II	− .09	4	−0.12	5
Cr II	(+0.06)	5	.....	.....

computed by Russell[1] to fill out certain partially known multiplets, are well represented. Equally striking is the absence of lines of the neutral atom.

The average displacements of various groups of lines are shown in Table II. Positive displacements are toward the red, negative toward the violet. These are based on the published wave-lengths, which include corrections for radial velocity. Blends in which a second line probably affects the measured position are omitted from the tabulation. Ordinary and forbidden iron lines, *Fe* II and [*Fe* II], have nearly the same mean displacement. The titanium lines appear to be shifted about half an angstrom toward the violet as compared with the iron lines. The chromium lines have much smaller displacements. One chromium line in Lunt's list (λ 4559.30) has a large positive displacement. The means with and without this line are shown in Table II.

[1] *Mt. Wilson Contr.*, No. 318; *Astrophysical Journal*, **64**, 194, 1926.

The multiplets formed by the new lines appear in Table III. The term values are those by Russell.[1] The wave-lengths of lines, given for convenience instead of wave-numbers, are in international angstroms in air. The intensities in η Carinae appear in parentheses.

TABLE III

FORBIDDEN MULTIPLETS IN *Fe* II

	a6D5 0.00	a6D4 384.80	a6D3 667.65	a6D2 862.55	a6D1 976.96
a6S3 23317.61	4287.40(10)	4359.34(10−)	4413.79(8)	4452.09(5)	4474.90(3)
b4P'3 20830.44	.....	4889.66(2)	4958.25	5006.65	.....
b4P'2 21811.93	.....	.....	4728.09(5)	4772.08	4798.28
b4P'1 22409.71	.....	.....	.....	4639.69(2)	4664.45
b4F'5 22637.15	4416.28(9−)	4492.65(?)	.....	.....	.....
b4F'4 22810.28	4382.76(0)	4457.96(4)	4514.92(?)	.....	.....
b4F'3 22939.21	.....	4432.48	4488.77(?)	4528.40	.....
b4F'2 23031.25	.....	.....	4470.30	4509.60	4533.00

	a4F'5 1872.56	a4F'4 2430.16	a4F'3 2837.91	a4F'2 3117.49	
b4F'5 22637.15	4814.55(5)	4947.40	.....	.....	.....
b4F'4 22810.28	4774.74(0)	4905.37(0)	5005.53	.....	.....
b4F'3 22939.21	.....	4874.54(0)	4973.42	5043.57	.....
b4F'2 23031.25	.....	.....	4950.75	5020.25	.....
a4G6 25428.78	4243.97(8)	4346.87(1)	.....	.....	.....
a4G5 25805.21	4177.22(0)	4276.87(5)	4352.80(?)	.....	.....
a4G4 25981.51	.....	4244.85(1)	4319.64(2)	4372.46(0)	.....
a4G3 26055.35	.....	.....	4305.90(1)	4358.38(?)	.....

The multiplets in Table III arise from transitions between low energy-levels of the ionized-iron atom. The corresponding terms are all "even," and combinations between them are forbidden by an empirical rule based upon all analyzed laboratory spectra. They may thus be regarded as stable or metastable states in which the ion

[1] *Ibid.*

remains a relatively long time if left to itself. The combinations, although not observed in the laboratory, are not, however, wholly impossible, and the low densities of stellar atmospheres, with the correspondingly great mean free times, may provide opportunities for them to occur.

The structures of the multiplets are similar to those of ordinary multiplets. The intensities behave, in general, in about the usual way. Table IV shows in condensed form the relationship of the stronger lines to the changes in the quantum numbers.

TABLE IV

INTENSITIES AND QUANTUM CHANGES

Multiplet	a^6D-a^6S	a^6D-b^4P'	a^6D-b^4F'	$a^4F'-b^4F'$	$a^4F'-a^4G$
Δk	+2	+1	−1	0	−1
Δj of strongest lines	+2	+1	0	0	−1

The agreement between Δk and Δj appears to be about the same as that shown by ordinary multiplets of ionized iron. The one case in which Δj differs from Δk is an intersystem combination. A modification of the rule concerning changes in the inner-quantum number is shown by the $a^4F'-a^4G$ multiplet in which the Δj's of observed lines are $-2, -1, 0$, instead of the usual $-1, 0, +1$. A more remarkable instance of the violation of the rule for the inner-quantum number is furnished by the a^6D-a^6S multiplet. Here a single ^6S term, having inner-quantum number 3, combines with ^6D levels having inner-quantum numbers 1–5, yielding five strong lines. The stronger lines are those for which changes in j and k have the same sign, in accord with the usual rule.

The relationship between the new forbidden lines and the ordinary iron spark lines is brought out by a partial Grotrian diagram in Figure 1. To simplify the diagram, one high level, b^4F, and several intersystem combinations are omitted. I am indebted to Miss Charlotte E. Moore for preparing the complete Grotrian diagram from which Figure 1 was taken.

The new lines arise through transitions from even terms of intermediate energy-levels to the two lowest terms a^6D and a^4F'. It is a striking fact that, with one exception, every calculated multiplet

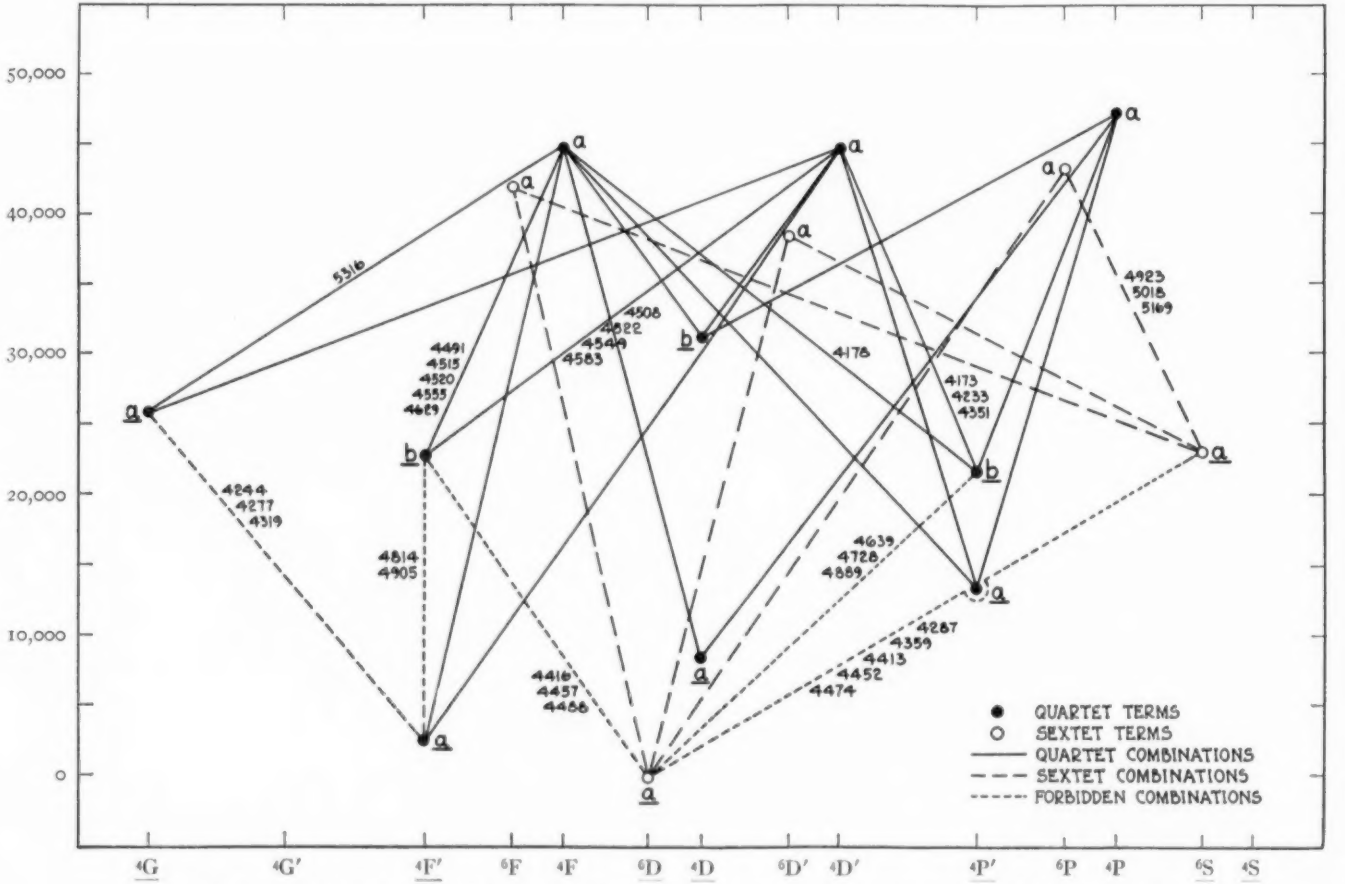

FIG. 1.—Partial Grotrian diagram of *Fe* II. The underlined terms are even, the others odd. The wave-lengths of the stronger lines are indicated for a number of multiplets.

of this kind between λ 4000 and λ 5000 is represented in η Carinae. The exception is $a^4F'-a^6S$, an intersystem combination where the azimuthal-quantum number would change by three. Every initial state of these newly recognized transitions is the final state of well-known lines of *Fe* II. These lines are in Table I, except λ 5316, which lies outside of the observed region.

Data concerning "forbidden" lines should aid physicists in the study of metastable states and in the interpretation of the combination rules. If every electronic transition has its own characteristic probability of occurrence at any instant (which may or may not be a function of the time since the arrival of the electron in the initial state), then the mean free time between collisions is a very important item in determining the relative intensities of various lines in the spectrum of a particular atom. Astronomical observations may thus supplement those of the laboratory by supplying data on line emission under very low densities. The character and intensity of the incident radiation may also play an important part in the duration of various electronic states. The problem can, of course, be worked both ways, and forbidden lines may thus perhaps yield information concerning conditions in the stars.

Fortunately the forbidden iron lines are known in several stellar spectra besides that of η Carinae. Some observations of these spectra are already on hand and will be presented in future *Contributions*. The relative behavior of the forbidden lines in various sources should be of considerable interest.

The present investigation was suggested by Bowen's success in identifying several of the stronger nebular lines with transitions from metastable states in oxygen and nitrogen atoms.

MOUNT WILSON OBSERVATORY
CARNEGIE INSTITUTION OF WASHINGTON
February 1928

ON THE PERIOD OF THE SPECTROSCOPIC BINARY 36 τ^9 ERIDANI

By CHARLES HUJER

ABSTRACT

The *period* of *36 τ^9 Eridani* was *re-examined* on the basis of observations recently published by the Lick Observatory and new plates lately secured at Yerkes Observatory. The mean *period* $0^d.85441$ previously found was *adjusted* to $0^d.85423$ to include the recent observations. As the previous results suggested that the period might be variable, the recent observations were compared with the earlier ones. The distribution of residuals indicated no secondary period.

Observations, being possible only near the meridian on account of the star's southern declination, made this case suitable for the use of the formula for the *alternative periods* $p_1 = p_3/(1-p_3)$, $p_2 = p_3/(2p_3-1)$, $p_3 = 0^d.85423$. In view of a large scattering p_2 was discarded; p_1, as well as p_3, gives a satisfactory velocity-curve, and either one can be used for determining the elements of the orbit. There is at present no way of deciding which is correct until a few spectrograms can be obtained at a longitude widely differing from that of the Yerkes Observatory. The elements were determined by Laves's hodographic method as modified by Pogo.

The recent volume on radial velocities of the *Publications of the Lick Observatory*[1] contains five observations of the radial velocity of

TABLE I

LICK OBSERVATIONS

DATE, G.C.T.	OBS.	QUAL.	VEL.	MEAN VEL.	PHASES			
					$p = 0^d.8544075$	$p_1 = 0^d.8542336$	$p_2 = 1^d.1978984$	$p_3 = 5^d.9542159$
1909 Jan. 23.09	P	.....	+40	+40	0.79	0.33	0.73	4.28
Aug. 17.39	M	.....	−19					
	H	.....	12	−15.5	.32	.76	0.99	2.18
Aug. 29.38	M	.....	26					
	H	.....	13	19.5	.35	.79	1.00	2.26
Dec. 21.08	P	.....	16					
	H	.....	15	15.5	.42	.02	0.90	2.83
1910 Jan. 13.10	Mo	.....	17					
	H	.....	−23	−20.0	0.37	0.83	1.16	2.03

The names of the observers are designated as follows: P = C. F. Paddock, M = J. H. Moore, H = Miss A. M. Hobe, Mo = Mrs. J. H. Moore.

36 τ^9 Eridani (α, $3^h55^m.7$; δ, $-24°18'$, 1900). Since in our previous paper on the orbit of this spectroscopic binary[2] it was found that the

[1] *Op. cit.*, **16**, 50, 1928.

[2] O. Struve and C. Hujer, *Astrophysical Journal*, **65**, 300, 1927.

period may be variable, it seemed desirable to check this by means of these Lick observations. Four of them fall in the year 1909 and one in 1910 and so form a continuation of a group of early Yerkes spectrograms made in 1908. The mean period $0^d.8544075$ as given in the paper by Struve and Hujer referred to above is in agreement with the Lick observations, these being shifted in the direction of smaller phases by $0^d.15$.

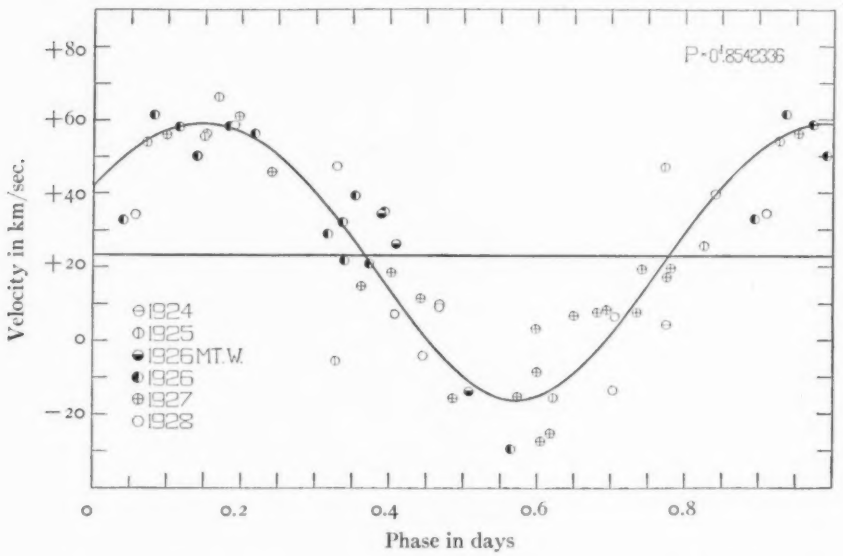

FIG. 1.—Velocity-curve of 36 τ^9 Eridani ($p_3=0^d.8542336$). Phases are counted from 1926 October 15.0. U.T.

A new series of observations has recently been obtained with the Bruce spectrograph. These, when plotted against the mean period, proved that the velocity-curve is shifted to the left by $0^d.1$.

Adjustment of the mean period.—The fact that our new observations were shifted by $0^d.1$ to the left led to an adjustment of the old period. As the mean separation of the new observations from the old ones is about 575 revolutions, the period was shortened by $0^d.00017$, which gave $p=0^d.85423$. This new period gives a satisfactory curve including all observations since 1924. When the early Yerkes observations together with those of the Lick Observatory

were plotted with this adjusted period, a good curve was obtained, but on account of the long interval of time between the early and recent observations, no attempt has been made further to adjust the period and to combine all observations since 1908.

An investigation of the distribution of the residuals was made for the purpose of finding some variability of long period. The adjusted curve was used for deriving the residuals. Considerable

TABLE II

NEW YERKES OBSERVATIONS

DATE, U.T.	OBS.	QUAL.	VEL.	PHASES			
				$P=0^d8544075$	$p_2=0^d8542336$	$p_3=1^d1978984$	$p_4=5^d9542159$
1928 Jan. 31.096.....	PBS	vg	+ 6.6	0.609	0.705	1.124	2.173
Feb. 4.108.....	HuS	f	− 4.0	.349	.446	0.344	0.771
Feb. 6.074.....	BHuS	g	−13.3	.606	.703	1.113	2.737
Feb. 10.049.....	BHu	g	+ 7.5	.309	.407	0.296	0.758
Feb. 10.110.....	HuS	f	9.4	.370	.468	.357	0.819
Feb. 19.026.....	BMP	f	39.5	.742	.842	.888	3.780
Feb. 19.095.....	BPS	g	34.1	.811	.056	.957	3.849
Mar. 3.042	σHuS	g	58.8	.087	.190	.727	4.888
Mar. 4.035.....	σHu	g	47.8	.226	.329	.522	5.881
Mar. 5.029.....	σHu	g	+ 9.7	0.365	0.468	0.318	0.921

The names of the observers and the quality of the plates are designated as follows: B=S.B. Barrett, σ=O. Struve, P=A. Pogo, M=W. W. Morgan, Hu=C. Hujer, S=F. R. Sullivan; vg=very good, g=good, f=fair, p=poor. The measures are by Hujer.

differences in the values of O.−C. were found even within the observations of the same night. The residuals were plotted against time but no periodicity could be found.

Alternative periods.—In view of the low southern declination of this star (−24°), our observations have necessarily been confined to small hour-angles. I have, therefore, followed a suggestion of Professor Struve and treated this star in a manner similar to that applied by him to the spectroscopic binary 27 Canis Majoris,[1] which presents a similar case. Under such conditions there always exist three distinct periods that will fit all observations almost equally well. This was first pointed out in connection with variable

[1] *Ibid.*, **66**, 113, 1927.

stars by C. Hoffmeister[1] and Harlow Shapley.[2] As has been shown by J. G Hagen,[3] $p_1 > p_2 > 1^d > p_3$ are expressed in the following way:

$$p_2 = p_1/(p_1 - 1) \qquad p_1 = p_2/(p_2 - 1)$$
$$p_3 = p_1/(p_1 + 1) \qquad p_1 = p_3/(1 - p_3)$$
$$p_2 = p_3/(2p_3 - 1) \qquad p_3 = p_2/(2p_2 - 1)$$

The values of p_1, p_2, p_3 must be expressed in sidereal time since our spectrographic observations were made at about the same hour-angles.

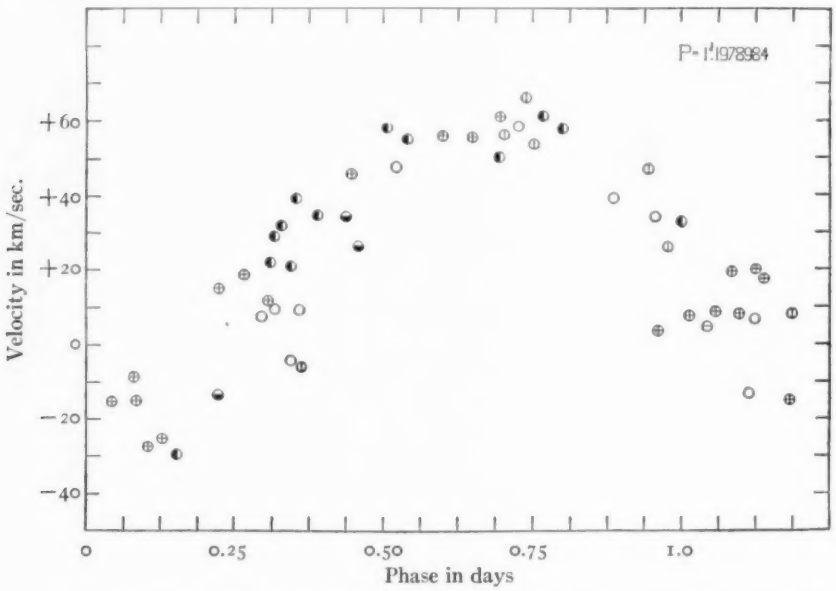

FIG. 2.—Velocity-curve of 36 τ^9 Eridani ($p_2 = 1^d.1978984$). Phases are counted from 1926 October 15.0. U.T. Observations of different seasons are indicated as in Fig. 1.

The period $p_3 = 0^d.85423$ gives a value of $0^d.85654$ in sidereal time. Thus there were computed two other periods, $p_2 = 1^d.20119$ in sidereal time $= 1^d.19790$ in mean solar time, and $p_1 = 5^d.97048$ in sidereal time $= 5^d.95422$ in mean solar time.

Velocity-curves.—The period p_2 was examined first and found to be impossible. Although the plotted observations have some tend-

[1] *Astronomische Nachrichten*, **196**, 399, 1913.

[2] *Ibid.*, p. 417, 1913. [3] *Die veränderlichen Sterne*, **1**, 624, 1920.

ency to form a curve, the scattering is far too great, and this period can safely be discarded.

The result is quite satisfactory in the case of the longer period p_1. Here we see that the observations give a definite curve with a scattering somewhat smaller than in the adjusted period, p_3. Now we have two periods: a short one p_3, and a long one p_1, correspond-

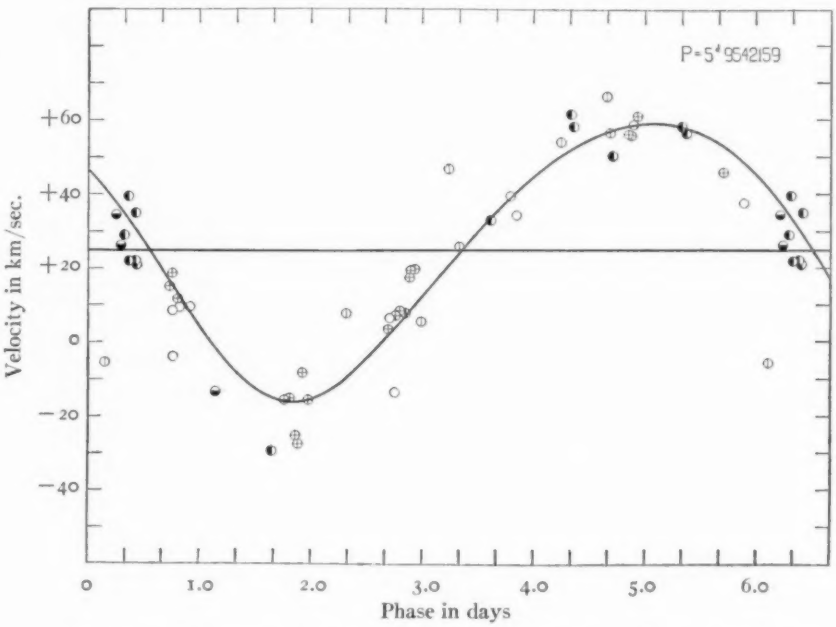

FIG. 3.—Velocity-curve of 36 τ^9 Eridani ($p_1 = 5^d.9542159$). Phases are counted from 1926 October 15.0. U.T. Observations of different seasons are indicated as in Fig. 1.

ing to two definite velocity-curves. Taking into consideration all the observations, there is no way to decide which of these two periods is the correct one.

The two Mount Wilson observations of September 15, 1926, referred to in our earlier paper,[1] seemed to show a slope corresponding to the shorter period. However, other series of plates, such as the one of January 15, 1927, show a slope that is much too small for the short period. The five-day period gives a better representation

[1] *Astrophysical Journal*, **65**, 302, 1927.

for this date. Evidently, the range in hour-angle during which this star is accessible in our northern latitudes is not sufficient to settle the question. Neither can a conclusion be drawn from the fact that both the Lick and the Mount Wilson observations were obtained at longitudes about 30° to the west of Williams Bay. They are sufficiently well represented by either period. It should be noted that the scattering is in both curves greater than would be expected

TABLE III

ORBITAL ELEMENTS

Element	Designation	$p_1 = 0^d8542336$	$p_1 = 5^d9542159$
Velocity of system	γ	+23.4 km/sec.	+25.0 km/sec.
Period	P	$0^d8542336$	$5^d9542159$
Eccentricity	e	0.052	0.115
Half-amplitude	K	37.5 km/sec.	37.5 km/sec.
Longitude of periastron	ω	180°	142°
Time of periastron	T	0^d572	1^d332
Major-semiaxis	$a \sin i$	440.000 km	3000.000 km
Mass function	$m_2^3 \sin^3 i_1 (m/+m_2)^2$	0.00047 ⊙	0.0324 ⊙

The phases are counted from 1926 October 15.000 U.T.

from the internal agreement of the measurements, but there is a slight advantage in favor of the five-day period.

It is unfortunate that practically all spectrographic observations are being made on the American continent. A few observations taken somewhere in India, Australia, or China would immediately settle the question of the period.

For the present it seems best to give both periods and to derive for each curve a set of elements. This was done by the hodographic method as proposed by Laves and modified by Pogo.[1]

YERKES OBSERVATORY
WILLIAMS BAY, WIS.
April 3, 1928

[1] *Ibid.*, **67**, 262, 1928.

BRIGHT IRON LINES IN THE SPECTRUM OF H.D. 45677[1]

By PAUL W. MERRILL

ABSTRACT

The *spectrum* of *H.D. 45677* is *B2* with *numerous* superposed *bright lines* due chiefly to hydrogen and ionized iron (*Fe* II). The *bright hydrogen lines* are double, with the component of longer wave-length the more intense. About half of the *bright iron lines* are *forbidden lines* recently recognized in the spectrum of η Carinae. The apparent *radial velocity* derived from the bright lines is +19 km/sec.; from the absorption lines, +25 km/sec.

Mrs. Fleming's discovery of bright hydrogen lines in the spectrum of H.D. 45677[2] was announced in 1898 in *Harvard Circular*, No. 32. A preliminary account of the spectrum as observed at Mount Wilson with a slit spectrograph has already been published.[3] Additional spectrograms have since been obtained, and the present article gives a more complete description of the spectrum, which is of special interest because of the presence of numerous emission lines of ionized iron, including about fifteen of the "forbidden" lines recently recognized in the spectrum of η Carinae.[4]

The plates listed in Table I were taken with a one-prism spectrograph and 18-inch camera. The 60-inch telescope was employed for the first four plates, the 100-inch for the others.

The strong underlying continuous spectrum has absorption lines of class B2. The helium lines are well marked and without noticeable bright portions. The enhanced magnesium line λ 4481 is present, but its intensity appears not to exceed one-third that of λ 4471, except on the last plate, where its relative intensity was estimated to be 0.4. Direct comparison of this plate, C 4489, with an earlier one, C 4121, supports the implication that λ 4481 is stronger on the later plate. The velocity derived from λ 4481 *Mg* is +27 km/sec.; from λ 4471 *He*, +25 km/sec.; and from five other helium lines, +25 km/sec.

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 355.

[2] B.D.−12°1500; R.A. 6^h23^m7, Dec. −13°0′ (1900); mag. 7.5. Remark in *Henry Draper Catalogue:* "The line *Hβ* is bright. *Hγ* is very hazy and may have a centre which is slightly brighter than other portions of the spectrum."

[3] *Publications of the Astronomical Society of the Pacific*, **37**, 163, 1925.

[4] *Mt. Wilson Contr.*, No. 354; *Astrophysical Journal*, **67**, 391, 1928.

Bright hydrogen lines are outstanding features of the spectrum. $H\alpha$, as shown by the last three plates and by an objective-prism photograph on March 5, 1927, is an extremely strong line. It is overexposed on Plate C 4191, on which the continuous spectrum near it is just visible.

The bright $H\beta$ and $H\gamma$ lines are double, as is very commonly the case in Be spectra. In the majority of such spectra the two bright components are of equal intensity, but H.D. 45677 is one of a number of stars in which the red component is the stronger, the intensity ratio of the components of $H\beta$ being about 2 to 1, and of $H\gamma$, 3 or 4 to 1. The ratios are not the same on all the photographs, however,

TABLE I

JOURNAL OF OBSERVATIONS OF H.D. 45677

Plate	Date	Remarks
γ 12235	1923 Oct. 25	Narrow
12510	1924 Feb. 21	
13141	Dec. 15	
13158	1925 Jan. 4	Wide
C 3540	Sept. 30	Focus poor
4016	1926 Sept. 17	
4121	Nov. 24	Includes red region
4191	1927 Feb. 18	Includes red region
4489	Oct. 14	Includes red region

as the intensities of the violet components appear to vary. With the dispersion employed the components of $H\alpha$ are not separated, but the measured position of the blend indicates that the violet component is about two-thirds as intense as the other. As usual in Be spectra, the bright portions of the hydrogen lines grow more intense, and the dark portions less intense, in passing from $H\delta$ to $H\alpha$. The measured positions of the bright components, expressed for convenience in terms of radial velocity (reduced to the sun), are given in Table II.

The chief interest in this spectrum, however, lies in the presence of numerous emission lines which may be ascribed to the ionized-iron atom. These and a few unidentified lines do not share the structure of the hydrogen lines, but are narrow, single lines, fairly well defined, although the edges are not perfectly sharp. About twenty well-known iron-spark lines are present, of which five or six are

strong enough to be measurable with some accuracy. Their displacements, reduced to the sun, are tabulated in Table III.

A large proportion of the remaining bright lines are forbidden lines of the ionized-iron atom not yet observed in the laboratory.[1] The mean displacement of a number of the stronger ones is +17 km/sec., in agreement with the lines in Table III.

TABLE II

POSITIONS OF BRIGHT COMPONENTS OF HYDROGEN LINES

	Violet Comp.	Red Comp.	Blend
Hα	.....	.....	+26 km/sec.
Hβ	−73 km/sec.	+98 km/sec.	.....
Hγ	−82	96	.....
Hδ	.....	+93	.....

TABLE III

MEASURES OF BRIGHT LINES OF *Fe* II

Line	Apparent Radial Velocity
λ 4233	+19 km/sec.
4549	24
4555	16
4583	16
4629	15
4924	21
11 other lines	+23
Mean	+19

Measurements of the bright lines are collected in Table IV. The wave-lengths are corrected for a radial velocity of +19 km/sec. The intensities are visual estimates.

Comparison of the spectrum of H.D. 45677 with that of *η* Carinae shows practically the same group of bright lines to be present in both objects, although the continuous spectrum is much stronger in H.D. 45677 than in the southern star. All lines in Table IV between λ 4068 and λ 5168 have been observed in *η* Carinae, and only the weaker lines of *η* Carinae are not found in the other star. The forbidden lines are relatively less intense in H.D. 45677. A comparative study of the intensities of the various lines will be made when data for other stars become available.

[1] *Mt. Wilson Contr.*, No. 354; *Astrophysical Journal*, **67**, 391, 1928.

TABLE IV

EMISSION LINES IN THE SPECTRUM OF H.D. 45677

I.A.	Int.	Identification
4068.56	2	68.62 *Neb.?*
.....	1	*Hδ*
4173.7±	0	73.48 *Fe* II
4178.5	0	78.87 *Fe* II, 77.22 [*Fe* II]?
4233.19	2	33.16 *Fe* II
4244.13	2	43.97 [*Fe* II], 44.85 [*Fe* II]?
4276.79	1	76.87 [*Fe* II]
4287.43	3	87.40 [*Fe* II]
4296.5±	0	96.56 *Fe* II
4319.7	0	19.64 [*Fe* II]
.....	4	*Hγ*
4352.3	1	51.77 *Fe* II, 52.80 [*Fe* II]
4359.15	3	59.34 [*Fe* II], 58.38 [*Fe* II]
4372.5	0	72.46 [*Fe* II]
4413.75	2	13.79 [*Fe* II]
4416.21	2	16.28 [*Fe* II], 16.81 *Fe* II
4451.9	1	52.09 [*Fe* II]
4458.0	0	57.96 [*Fe* II]
4508.5±	0	08.29 *Fe* II
4515.0	0	15.34 *Fe* II
4549.58	2	49.48 *Fe* II, 49.64 *Ti* II
4555.86	1.5	55.90 *Fe* II
4571.2±	0	71.98 *Ti* II?
4576.5±	0	76.31 *Fe* II
4583.70	3	83.84 *Fe* II
4629.44	2	29.33 *Fe* II
4727.8±	0	28.09 [*Fe* II]
4814.4	1	14.55 [*Fe* II]
.....	10	*Hβ*
4889.9±	0	89.66 [*Fe* II]
4923.84	3	23.92 *Fe* II
5018.4	4	18.44 *Fe* II
5158.4	2	58.05 [*Fe* II]
5168.9	3	69.03 *Fe* II
5197.7	2	97.56 *Fe* II
5234.2±	1	34.62 *Fe* II
5261	0	.....
5274.9 broad or double	2	73.39 [*Fe* II], 76.01 *Fe* II
5316.6	3	16.62 *Fe* II
5325	0	25.56 *Fe* II
5333	1	.....
5375	1	.....
6300.1	4	*Neb.?*
6317	1	.....
6364	2	*Neb.?*
6382	1	.....
6456	0	56.39 *Fe* II
.....	40	*Hα*

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
March 1928

INDEX TO VOLUME LXVII

SUBJECTS

PAGE

Atmosphere at Eclipse of January 24, 1925, Water Vapor in. *Edison Pettit* and *Seth B. Nicholson* 183
Binary 4 β Trianguli, Orbit of Spectroscopic. *O. Struve* and *A. Pogo* . . 336
Binary, H.D. 163181, Spectroscopic. *Milton L. Humason* and *Seth B. Nicholson* 341
Binary 36 τ^9 Eridani, Period of Spectroscopic. *Charles Hujer* . . . 399
Calcium, Further Work on Interstellar. *Otto Struve* 353
η Carinae, Identification of Lines in Spectrum of. *Paul W. Merrill* . . 391
Chromium, Arc Spectrum of. *Donald Foster* 16
Contributors, Notice to 352
α Coronae Borealis, Variable Radial Velocity of. *J. Hartmann* . . . 269
Distribution, Systematic Deviations from Mean Stellar. *Frederick H. Seares* and *Mary C. Joyner* 24
Eclipse of January 24, 1925, Water-Vapor in Atmosphere at. *Edison Pettit* and *Seth B. Nicholson* 183
Einstein's Theory, Gravitational Displacement in Solar Spectrum Predicted by. *Charles E. St. John* 195
Equilibrium, Certain Equations in Theory of Radiative. *K. P. Williams* 296
36 τ^9 Eridani, Period of Spectroscopic Binary. *Charles Hujer* . . . 399
Galactic System, Structural Features of. *Frederick H. Seares* . . . 123
Halogen Derivatives of Methane, Infra-Red Absorption Spectra of. *M. A. Easley, L. Fenner,* and *B. J. Spence* 185
H.D. 45677, Bright Iron Lines in Spectrum of. *Paul W. Merrill* . . 405
Hydrogen, Secondary Spectrum of. *H. G. Gale, G. S. Monk,* and *K. O. Lee* 89
Interstellar Calcium, Further Work on. *Otto Struve* 353
Iron Arc, Effect of Pressure on Spectrum of. *Harold D. Babcock* . . . 240
Iron Lines in Spectrum of H.D. 45677, Bright. *Paul W. Merrill* . . 405
Laves, Hodographic Method of, for Determining Elements of Spectroscopic Orbits, Use of. *Alexander Pogo* 262
Lines in Sodium Vapor, Width of the D Absorption. *Arthur S. Fairley* . 114
RR Lyrae, Period and Radial Velocity of. *Roscoe F. Sanford* . . . 319
Methane, Infra-Red Absorption Spectra of Halogen Derivatives of. *M. A. Easley, L. Fenner,* and *B. J. Spence* 185
Monoceros, Nebulosities in. *Frank E. Ross* 281
Nebulae, Origin of Nebular Lines and Structure of Planetary. *I. S. Bowen* 1
Nebulosities in Monoceros, Taurus, and Perseus. *Frank E. Ross* . . 281

PAGE

Nitrogen Peroxide Absorption Spectrum, Wave-Lengths in. *Lois C. K. Carwile* 184
Orbit of Spectroscopic Binary 4 β Trianguli. *O. Struve* and *A. Pogo* . 336
Orbits, Use of Hodographic Method of Laves for Determining Elements of Spectroscopic. *Alexander Pogo* 262
Perseus, Nebulosities in. *Frank E. Ross* 281
Radial Velocity of α Coronae Borealis, Variable. *J. Hartmann* . . . 269
Radial Velocity of Cluster-Type Variable RR Lyrae. *Roscoe F. Sanford* . 319
Radiative Equilibrium, Certain Equations in Theory of. *K. P. Williams* . 296
Reviews:
Andrade, E. N. da C. *The Structure of the Atom* (Harvey B. Lemon) . 272
Baly, E. C. C. *Spectroscopy* (Arthur S. King) 347
Bauschinger, Julius. *Die Bahnbestimmung der Himmelskörper* (G. Van Biesbroeck) 279
Crump, C. C. Review of: *Astronomy*, H. N. Russell, R. S. Dugan, and J. Q. Stewart 274
Eddington, A. S. *The Internal Constitution of the Stars* (Henry Norris Russell) 83
Kemble, Edwin C., Raymond T. Birge, Walter F. Colby, F. Wheeler Loomis, and Leigh Page. *Molecular Spectra in Gases* (William W. Watson) 275
Kopff, August (ed.). *Müller-Pouillets Lehrbuch der Physik* (Otto Struve) 277
Russell, H. N., R. S. Dugan, and J. Q. Stewart. *Astronomy* (C. C. Crump) 274
RY Scuti, Peculiar Bright-Line Spectrum of. *Paul W. Merrill* . . . 179
Sodium Vapor, Width of the D Absorption Lines in. *Arthur S. Fairley* . 114
Solar Spectrum, Gravitational Displacement in. *Charles E. St. John* . . 195
Spectra of Halogen Derivatives of Methane, Infra-Red Absorption. *M. A. Easley, L. Fenner*, and *B. J. Spence* 185
Spectra of Class B, Wave-Lengths in Stellar. *Sebastian Albrecht* . . 305
H.D. 163181, Spectroscopic Binary. *Milton L. Humason* and *Seth B. Nicholson* 341
Spectrum of Chromium, Arc. *Donald Foster* 16
Spectrum of Hydrogen, Secondary. *H. G. Gale, G. S. Monk*, and *K. O. Lee* 89
Spectrum of RY Scuti, Peculiar Bright-Line. *Paul W. Merrill* . . . 179
Spectrum, Nitrogen Peroxide Absorption. *Lois C. K. Carwile* . . . 184
Spectrum, Gravitational Displacement in Solar. *Charles E. St. John* . 195
Spectrum of Iron Arc, Effect of Pressure on. *Harold D. Babcock* . . 240
Spectrum of Cepheid Variable U Vulpeculae. *Roscoe F. Sanford* . . 326
Spectrum of η Carinae, Identification of Lines in. *Paul W. Merrill* . . 391
Spectrum of H.D. 45677, Bright Iron Lines in. *Paul W. Merrill* . . 405
Stellar Distribution, Systematic Deviations from Mean. *Frederick H. Seares* and *Mary C. Joyner* 24

PAGE
Taurus, Nebulosities in. *Frank E. Ross* 281
4 β Trianguli, Orbit of Spectroscopic Binary. *O. Struve* and *A. Pogo* . 336
Variable RR Lyrae, Period and Radial Velocity of. *Roscoe F. Sanford* . 319
Variable U Vulpeculae, Period, Velocity-Curve, and Spectrum of Cepheid. *Roscoe F. Sanford* 326
U Vulpeculae, Period, Velocity-Curve, and Spectrum of. *Roscoe F. Sanford* 326
Water-Vapor in Atmosphere at Eclipse of January 24, 1925. *Edison Pettit* and *Seth B. Nicholson* 183

INDEX TO VOLUME LXVII

AUTHORS

PAGE

ALBRECHT, SEBASTIAN. Wave-Lengths in Stellar Spectra of Class B . . 305

BABCOCK, HAROLD D. The Effect of Pressure on the Spectrum of the Iron Arc 240

BOWEN, I. S. The Origin of the Nebular Lines and the Structure of the Planetary Nebulae 1

CARWILE, LOIS C. K. Note on Wave-Lengths in the Nitrogen Peroxide Absorption Spectrum 184

EASLEY, M. A., L. FENNER, and B. J. SPENCE. The Infra-Red Absorption Spectra of the Halogen Derivatives of Methane 185

FAIRLEY, ARTHUR S. The Width of the D Absorption Lines in Sodium Vapor 114

FENNER, L., B. J. SPENCE, and M. A. EASLEY. The Infra-Red Absorption Spectra of the Halogen Derivatives of Methane 185

FOSTER, DONALD. Wave-Lengths in the Arc Spectrum of Chromium in International Units 16

GALE, H. G., G. S. MONK, and K. O. LEE. Wave-Lengths in the Secondary Spectrum of Hydrogen 89

HARTMANN, J. Measures of the Variable Radial Velocity of α Coronae . 269

HUJER, CHARLES. On the Period of the Spectroscopic Binary 36 τ^9 Eridani 399

HUMASON, MILTON L., and SETH B. NICHOLSON. H.D. 163181, A Spectroscopic Binary 341

JOYNER, MARY C., and FREDERICK H. SEARES. Systematic Deviations from the Mean Stellar Distribution 24

KING, ARTHUR S. Review of: *Spectroscopy*, E. C. C. Baly 347

LEE, K. O., G. S. MONK, and H. G. GALE. Wave-Lengths in the Secondary Spectrum of Hydrogen 89

LEMON, HARVEY B. Review of: *The Structure of the Atom*, E. N. da C. Andrade 272

MERRILL, PAUL W. The Peculiar Bright-Line Spectrum of RY Scuti . 179

MERRILL, PAUL W. Identification of Lines in the Spectrum of η Carinae 391

MERRILL, PAUL W. Bright Iron Lines in the Spectrum of H.D. 45677 . 405

MONK, G. S., H. G. GALE, and K. O. LEE. Wave-Lengths in the Secondary Spectrum of Hydrogen 89

NICHOLSON, SETH B., and MILTON L. HUMASON. H.D. 163181, A Spectroscopic Binary 341

PAGE

NICHOLSON, SETH B., and EDISON PETTIT. The Effective Amount of Water-Vapor in the Atmosphere at the Eclipse of January 24, 1925 . 183

PETTIT, EDISON, and SETH B. NICHOLSON. The Effective Amount of Water-Vapor in the Atmosphere at the Eclipse of January 24, 1925 . 183

POGO, ALEXANDER. On the Use of the Hodographic Method of Laves for Determining Elements of Spectroscopic Orbits 262

POGO, A., and O. STRUVE. Orbit of the Spectroscopic Binary 4 β Trianguli 336

ROSS, FRANK E. Nebulosities in Monoceros, Taurus, and Perseus . . 281

RUSSELL, HENRY NORRIS. Review of: *The Internal Constitution of the Stars*, A. S. Eddington 83

ST. JOHN, CHARLES E. Evidence for the Gravitational Displacement of Lines in the Solar Spectrum Predicted by Einstein's Theory . . 195

SANFORD, ROSCOE F. On the Period and Radial Velocity of the Cluster-Type Variable RR Lyrae 319

SANFORD, ROSCOE F. On the Period, Velocity-Curve, and Spectrum of the Cepheid Variable U Vulpeculae 326

SEARES, FREDERICK H. Some Structural Features of the Galactic System 123

SEARES, FREDERICK H., and MARY C. JOYNER. Systematic Deviations from the Mean Stellar Distribution 24

SPENCE, B. J., M. A. EASLEY, and L. FENNER. The Infra-Red Absorption Spectra of the Halogen Derivatives of Methane 185

STRUVE, OTTO. Review of: *Müller-Pouillets Lehrbuch der Physik*, August Kopff (ed.) 277

STRUVE, OTTO. Further Work on Interstellar Calcium 353

STRUVE, O., and A. POGO. Orbit of the Spectroscopic Binary 4 β Trianguli 336

VAN BIESBROECK, G. Review of: *Die Bahnbestimmung der Himmelskörper*, Julius Bauschinger 279

WATSON, WILLIAM W. Review of: *Molecular Spectra in Gases*, Edwin C. Kemble, Raymond T. Birge, Walter F. Colby, F. Wheeler Loomis, and Leigh Page 275

WILLIAMS, K. P. A Comment on Certain Equations in the Theory of Radiative Equilibrium 296

ERRATA

Vol. **67**, No. 4, May, 1928, article on "The Period and Radial Velocity of the Cluster-Type Variable RR Lyrae," by Roscoe F. Sanford:

Page 322, fourth line from top, *omit* rest of sentence after the word "figure."

Page 323, Figure 1, third line of the caption, *interchange* the letters *A* and *B*.

Page 324, third line below Table II, *for* "where the two broken . . . . are plotted" *read* "that in both cases the curves from the observations of one observatory fail to fit the observations from the other."

INDEX TO VOLUME LXVII

AUTHORS

PAGE

ALBRECHT, SEBASTIAN. Wave-Lengths in Stellar Spectra of Class B . . 305

BABCOCK, HAROLD D. The Effect of Pressure on the Spectrum of the Iron Arc 240

BOWEN, I. S. The Origin of the Nebular Lines and the Structure of the Planetary Nebulae 1

CARWILE, LOIS C. K. Note on Wave-Lengths in the Nitrogen Peroxide Absorption Spectrum 184

EASLEY, M. A., L. FENNER, and B. J. SPENCE. The Infra-Red Absorption Spectra of the Halogen Derivatives of Methane 185

FAIRLEY, ARTHUR S. The Width of the D Absorption Lines in Sodium Vapor 114

FENNER, L., B. J. SPENCE, and M. A. EASLEY. The Infra-Red Absorption Spectra of the Halogen Derivatives of Methane 185

FOSTER, DONALD. Wave-Lengths in the Arc Spectrum of Chromium in International Units 16

GALE, H. G., G. S. MONK, and K. O. LEE. Wave-Lengths in the Secondary Spectrum of Hydrogen 89

HARTMANN, J. Measures of the Variable Radial Velocity of α Coronae . 269

HUJER, CHARLES. On the Period of the Spectroscopic Binary 36 τ^9 Eridani 309

HUMASON, MILTON L., and SETH B. NICHOLSON. H.D. 163181, A Spectroscopic Binary 341

JOYNER, MARY C., and FREDERICK H. SEARES. Systematic Deviations from the Mean Stellar Distribution 24

KING, ARTHUR S. Review of: *Spectroscopy*, E. C. C. Baly 347

LEE, K. O., G. S. MONK, and H. G. GALE. Wave-Lengths in the Secondary Spectrum of Hydrogen 89

LEMON, HARVEY B. Review of: *The Structure of the Atom*, E. N. da C. Andrade 272

MERRILL, PAUL W. The Peculiar Bright-Line Spectrum of RY Scuti . 179

MERRILL, PAUL W. Identification of Lines in the Spectrum of η Carinae 391

MERRILL, PAUL W. Bright Iron Lines in the Spectrum of H.D. 45677 . 405

MONK, G. S., H. G. GALE, and K. O. LEE. Wave-Lengths in the Secondary Spectrum of Hydrogen 89

NICHOLSON, SETH B., and MILTON L. HUMASON. H.D. 163181, A Spectroscopic Binary 341

PAGE

NICHOLSON, SETH B., and EDISON PETTIT. The Effective Amount of Water-Vapor in the Atmosphere at the Eclipse of January 24, 1925 . 183

PETTIT, EDISON, and SETH B. NICHOLSON. The Effective Amount of Water-Vapor in the Atmosphere at the Eclipse of January 24, 1925 . 183

POGO, ALEXANDER. On the Use of the Hodographic Method of Laves for Determining Elements of Spectroscopic Orbits 262

POGO, A., and O. STRUVE. Orbit of the Spectroscopic Binary 4 β Trianguli 336

ROSS, FRANK E. Nebulosities in Monoceros, Taurus, and Perseus . . 281

RUSSELL, HENRY NORRIS. Review of: *The Internal Constitution of the Stars*, A. S. Eddington 83

ST. JOHN, CHARLES E. Evidence for the Gravitational Displacement of Lines in the Solar Spectrum Predicted by Einstein's Theory . . 195

SANFORD, ROSCOE F. On the Period and Radial Velocity of the Cluster-Type Variable RR Lyrae 319

SANFORD, ROSCOE F. On the Period, Velocity-Curve, and Spectrum of the Cepheid Variable U Vulpeculae 326

SEARES, FREDERICK H. Some Structural Features of the Galactic System 123

SEARES, FREDERICK H., and MARY C. JOYNER. Systematic Deviations from the Mean Stellar Distribution 24

SPENCE, B. J., M. A. EASLEY, and L. FENNER. The Infra-Red Absorption Spectra of the Halogen Derivatives of Methane 185

STRUVE, OTTO. Review of: *Müller-Pouillets Lehrbuch der Physik*, August Kopff (ed.) 277

STRUVE, OTTO. Further Work on Interstellar Calcium 353

STRUVE, O., and A. POGO. Orbit of the Spectroscopic Binary 4 β Trianguli 336

VAN BIESBROECK, G. Review of: *Die Bahnbestimmung der Himmelskörper*, Julius Bauschinger 279

WATSON, WILLIAM W. Review of: *Molecular Spectra in Gases*, Edwin C. Kemble, Raymond T. Birge, Walter F. Colby, F. Wheeler Loomis, and Leigh Page 275

WILLIAMS, K. P. A Comment on Certain Equations in the Theory of Radiative Equilibrium 296

ERRATA

Vol. **67**, No. 4, May, 1928, article on "The Period and Radial Velocity of the Cluster-Type Variable RR Lyrae," by Roscoe F. Sanford:

Page 322, fourth line from top, *omit* rest of sentence after the word "figure."

Page 323, Figure 1, third line of the caption, *interchange* the letters *A* and *B*.

Page 324, third line below Table II, *for* "where the two broken . . . . are plotted" *read* "that in both cases the curves from the observations of one observatory fail to fit the observations from the other."

JUL 1 1 1928

VOLUME LXVII NUMBER 5

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

Edited by

GEORGE E. HALE
Mount Wilson Observatory of the Carnegie Institution of Washington

EDWIN B. FROST
Yerkes Observatory of the University of Chicago

HENRY G. GALE
Ryerson Physical Laboratory of the University of Chicago

JUNE 1928

FURTHER WORK ON INTERSTELLAR CALCIUM - - - *Otto Struve* 353

IDENTIFICATION OF LINES IN THE SPECTRUM OF η CARINAE - *Paul W. Merrill* 391

ON THE PERIOD OF THE SPECTROSCOPIC BINARY 36 τ^9 ERIDANI *Charles Hujer* 399

BRIGHT IRON LINES IN THE SPECTRUM OF H.D. 45677 - - *Paul W. Merrill* 405

INDEX - - - - - - - - - - - - - - 409

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS, U.S.A.

THE CAMBRIDGE UNIVERSITY PRESS, LONDON
THE MARUZEN COMPANY, LIMITED, TOKYO
THE COMMERCIAL PRESS, LIMITED, SHANGHAI

June 1928 Vol. LXVII, No. 5

THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

Edited by

GEORGE E. HALE
Mount Wilson Observatory of the Carnegie Institution of Washington

EDWIN B. FROST
Yerkes Observatory of the University of Chicago

HENRY G. GALE
Ryerson Physical Laboratory of the University of Chicago

WITH THE COLLABORATION OF

WALTER S. ADAMS, Mount Wilson Observatory
JOSEPH S. AMES, Johns Hopkins University
ARISTARCH BELOPOLSKY, Observatoire de Pulkovo
WILLIAM W. CAMPBELL, Lick Observatory
HENRY CREW, Northwestern University
CHARLES FABRY, Université de Paris
ALFRED FOWLER, Imperial College, London
CHARLES S. HASTINGS, Yale University
HEINRICH KAYSER, Universität Bonn
ALBERT A. MICHELSON, University of Chicago
ROBERT A. MILLIKAN, Institute of Technology, Pasadena
HUGH F. NEWALL, Cambridge University
HENRY N. RUSSELL, Princeton University
FRANK SCHLESINGER, Yale Observatory
SIR ARTHUR SCHUSTER, Twyford
FREDERICK H. SEARES, Mount Wilson Observatory

The Astrophysical Journal is published by the University of Chicago at the University of Chicago Press, 5750 Ellis Avenue, Chicago, Illinois, during each month except February and August. ¶ The subscription price is $6.00 a year; the price of single copies is 75 cents. Orders for service of less than a half-year will be charged at the single-copy rate. ¶ Postage is prepaid by the publishers on all orders from the United States, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Dominican Republic, Canary Islands, El Salvador, Argentina, Bolivia, Brazil, Colombia, Chile, Costa Rica, Ecuador, Guatemala, Honduras, Nicaragua, Peru, Hayti, Uruguay, Paraguay, Hawaiian Islands, Philippine Islands, Guam, Samoan Islands, Balearic Islands, and Spain. ¶ Postage is charged extra as follows: for Canada and Newfoundland, 30 cents on annual subscriptions (total $6.30); on single copies, 3 cents (total 78 cents); for all other countries in the Postal Union, 50 cents on annual subscriptions (total $6.50), on single copies 5 cents (total 80 cents). ¶ Patrons are requested to make all remittances payable to The University of Chicago Press, in postal or express money orders or bank drafts.

The following are authorized to quote the prices indicated:

For the British Empire: The Cambridge University Press, Fetter Lane, London, E.C. 4. Yearly subscriptions, including postage, £1 12*s.* 6*d.* each; single copies, including postage, 4*s.* each.

For China: The Commercial Press, Ltd., Paoshon Road, Shanghai. Yearly subscriptions, $6.00; single copies, 75 cents, or their equivalents in Chinese money. Postage extra, on yearly subscriptions 50 cents, on single copies 5 cents.

Claims for missing numbers should be made within the month following the regular month of publication. The publishers expect to supply missing numbers free only when losses have been sustained in transit, and when the reserve stock will permit.

Business Correspondence should be addressed to The University of Chicago Press, Chicago, Illinois.

Communications for the editors and manuscripts should be addressed to the Editors of THE ASTROPHYSICAL JOURNAL, Yerkes Observatory, Williams Bay, Wisconsin.

The cable address is "Observatory, Williamsbay, Wisconsin."

The articles in this Journal are indexed in the *International Index to Periodicals*, New York, N.Y.

Entered as second-class matter, January 17, 1895, at the Post-office at Chicago, Ill., under the act of March 3, 1879.
Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on July 15, 1918.

PRINTED IN THE U.S.A.

Publications of
The YERKES OBSERVATORY

Vol. I. **General Catalogue of Double Stars.** With illustrations. By SHERBURNE WESLEY BURNHAM. 296 pages, cloth, postpaid $4.15; *net* $4.00

Vol. II. **The Decennial Papers on Astronomy and Astrophysics.** 414 pages and 29 plates, cloth, postpaid $6.20; *net* 6.00

Vol. III. (Part I.) **The Rumford Spectroheliograph of the Yerkes Observatory.** By GEORGE E. HALE and FERDINAND ELLERMAN. 26 pages and 15 plates, paper, postpaid 85 cents; *net* 75

(Part II.) **The Spectrum of the High Potential Discharge between Metallic Electrodes in Liquids and in Gases at High Pressures.** By GEORGE E. HALE and NORTON A. KENT. 42 pages and 8 plates, paper, postpaid 85 cents; *net* 75

(Part III.) **The Rotation Period of the Sun.** By PHILIP FOX. 136 pages, postpaid $2.60; *net* 2.50

(Part IV.) **The Forms and Motions of Solar Prominences.** By EDISON PETTIT. 34 pages and 11 plates, paper, postpaid $1.35; *net* 1.25

Vol. IV. (Part I.) **Stellar Parallaxes Derived from Photographs Made with the 40-inch Refractor.** By FREDERICK SLOCUM, ALFRED MITCHELL, OLIVER J. LEE, ALFRED H. JOY, and GEORGE VAN BIESBROECK. 68 pages and 2 plates, paper, postpaid $1.60; *net* . 1.50

(Part II.) **Photographic Investigations of Faint Nebulae.** By EDWIN P. HUBBLE. 89 pages, paper, postpaid 85 cents; *net* . . .75

(Part III.) **Parallaxes of Fifty Stars.** By GEORGE VAN BIESBROECK and HANNAH STEELE PETTIT. 36 pages, paper, postpaid $1.54; *net* 1.50

(Part IV.) **Zone +45° of Kapteyn's Selected Areas: Parallaxes and Proper Motions of 1041 Stars.** By OLIVER JUSTIN LEE. 67 pages, paper, postpaid $1.55; *net* 1.50

(Part V.) **A Comparison of the Photometric Fields of the 6-inch Doublet, 24-inch Reflector, and 40-inch Refractor of the Yerkes Observatory, with Some Investigation of the Astrometric Field of the Reflector.** By ALICE HALL FARNSWORTH. 37 pages, paper, postpaid $1.55; *net* 1.50

(Part VI.) **Photometric Observations of 1550 Stars in the Kapteyn Areas.** By JOHN ADELBERT PARKHURST. 62 pages, paper, postpaid $1.60; *net* 1.50

Vol. V. (Part I.) **Measurements of Double Stars.** By GEORGE VAN BIESBROECK. 265 pages, paper, postpaid $3.15; *net* 3.00

(Part II.) **Definitive Orbit of Comet Delavan.** By GEORGE VAN BIESBROECK. 36 pages, paper, postpaid $1.60; *net* 1.50

THE UNIVERSITY OF CHICAGO PRESS
CHICAGO . . . . . ILLINOIS

Publishers: G. E. STECHERT & CO., New York—DAVID NUTT, London—FÉLIX ALCAN, Paris—AKAD VERLAGSGESELLSCHAFT, Leipzig—NICOLA ZANICHELLI, Bologna—RUIZ HERMANOS, Madrid—RENASCENÇA PORTUGUESA, Porto—THE MARUZEN COMPANY, Tokyo

"SCIENTIA"

INTERNATIONAL REVIEW OF SCIENTIFIC SYNTHESIS

Published every month (each number containing 100 to 120 pages)

Editor: **EUGENIO RIGNANO**

IS THE ONLY REVIEW the contributors to which are really international.

IS THE ONLY REVIEW that has a really world-wide circulation.

IS THE ONLY REVIEW of scientific synthesis and unification that deals with the fundamental questions of all sciences: the history of the sciences, mathematics, astronomy, geology, physics, chemistry, biology, psychology and sociology.

IS THE ONLY REVIEW therefore which, while immediately interesting students of mathematics, astronomy, astrophysics and physics, by its numerous and important articles and reports relating to these sciences, presents them also the means of knowing, in a summary and synthetic form, the chief problems of all the other branches of knowledge.

IS THE ONLY REVIEW that among its contributors can boast of the most illustrious men of science in the whole world. A list of more than 350 of these is given in each number.

The articles are published in the language of their authors, and every number has *a supplement containing the French translation of all the articles that are not French.* The review is thus completely accessible to those who know only French. (*Write for a free copy* to the General Secretary of "Scientia," Milan, sending 12 cents in stamps of your country, merely to cover packing and postage.)

SUBSCRIPTION: $10, post free OFFICE: Via A. De Togni Milan (116)

General Secretary: DR. PAOLO BONETTI

Cambridge University Press

The Internal Constitution of the Stars. By A. S. EDDINGTON, M.A., LL.D., D.Sc., F.R.S. Royal 8vo. $8.50.

Problems of Cosmogony and Stellar Dynamics. By J. H. JEANS, M.A., F.R.S. Adams Prize Essay, 1917. With 5 plates. Royal 8vo. $8.00.

Some Problems of Geodynamics. By A. E. H. LOVE, M.A., D.Sc., F.R.S. Adams Prize Essay, 1911. Second Impression. Royal 8vo. $6.75.

The Combination of Observations. By D. BRUNT, M.A., B.Sc., Second Impression. Demy 8vo. $4.80.

The Earth: Its Origin, History, and Physical Constitution. By H. JEFFREYS, M.A., D.Sc. Royal 8vo. $5.50.

The Founders of Seismology. By CHARLES DAVISON, Sc.D., F.G.S. With 11 illustrations. Demy 8vo. $4.25

Published by the Cambridge University Press (England)
Sold by The Macmillan Company, Agents in the United States
60 Fifth Avenue, New York City